

***Report No. UT-03.34***

***FLEXURAL PERFORMANCE OF  
RETROFITTED REINFORCED  
CONCRETE CANTILEVERED  
BENT CAPS – PART 2***

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<b>16. Abstract</b> Five reinforced concrete bridge bents constructed in 1963 were obtained from the demolition of I-15 in Utah and one bent was newly constructed to the specifications of the existing bents. The bents were retrofitted using varying methods. The methods included concrete patches, epoxy crack injection, and carbon fiber reinforced plastic wraps. After the bents were repaired, their cantilevers were tested to failure. For the bents tested, the concrete patches did not conclusively affect the capacity of the bents, and were therefore unnecessary for structural purposes, but served more of a cosmetic and visual confidence need. The epoxy crack injection did not restore the strength or stiffness of the bent, but it still is a viable repair method of sealing cracks to protect the reinforcement from corrosion. The CFRP wraps were successful in strengthening and stiffening the bridge bents. The CFRP wrapped bents were about twice as stiff as the other bents tested.					
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## EXECUTIVE SUMMARY

Five reinforced concrete bridge bents constructed in 1963 were obtained from the demolition of I-15 in Utah and one bent was newly constructed to the specifications of the existing bents. The bents were retrofitted using varying methods. The methods included concrete patches, epoxy crack injection, and carbon fiber reinforced plastic wraps. After the bents were repaired, their cantilevers were tested to failure. For the bents tested, the concrete patches did not conclusively affect the capacity of the bents, and were therefore unnecessary for structural purposes, but served more of a cosmetic and visual confidence need. The epoxy crack injection did not restore the strength or stiffness of the bent, but it still is a viable repair method of sealing cracks to protect the reinforcement from corrosion. The CFRP wraps were successful in strengthening and stiffening the bridge bents. The CFRP wrapped bents were about twice as stiff as the other bents tested.

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## **1. Introduction**

### **1.1 Scope of Work**

The cantilevers of eight reinforced concrete bridge bents were tested to determine (1) the effects of deterioration on these bents and (2) the effects of different repair methods on the bents. Understanding the nature of the deteriorating bents and the effects of repairing the bents will help to find viable methods of repair, which can be less costly than replacing the bents. The repair methods tested were concrete patches, epoxy injection of cracks, and carbon fiber reinforced polymer wraps (CFRP). Six of the bents (15N, 15S, 12N, 12S, 13N, and 13S) were old, having been designed and built in the 1960's, and two of the bents (1N and 2N) were newly constructed to the same specifications as the old bents. The existing bents were obtained from the 6<sup>th</sup> South viaduct in Salt Lake City, Utah. During the summer of 1999, the viaduct was torn down and replaced as part of the I-15 reconstruction (Rowe, 2001). Figure 1.1 shows three of the bents and Figure 1.2 shows the north cantilever of Bent 15N.

Rowe (2001) undertook the first stage of this project by testing two cantilevers to failure—one old (12S) and one new (1N), and two cantilevers to their approximate yield point—one old (12N) and one new (2N). The response and behavior of the bents were then compared to determine if deterioration significantly affects the strength and performance of the bridge bents. Rowe also predicted the shear and flexural capacities of the bents. His predictions are summarized in Table 1.1. For a more detailed discussion on these predicted values, see Rowe, 2001.

This report covers the second stage of the project—to determine the effects of different repair methods on the bents. Bents 15N, 15S, and 12N were repaired with concrete patches and Bent 2N was repaired by injecting its cracks with epoxy. Bents 13N and 13S was repaired with a concrete patch and then wrapped with carbon fiber reinforced polymer (CFRP).

The purpose of testing was to determine the effects of the repair methods on the bents by observing their behavior and comparing their strength, stiffness, yield point, and crack growth.

## **1.2 Literature Review**

Three different methods of repair were used to determine their effects on rehabilitating deteriorated bridge bents. These methods are concrete patches, epoxy injection, and carbon fiber reinforced polymer. Significant research has been conducted and evaluated using these repair methods.

### **1.2.1 Concrete Patch**

A concrete patch is replacing concrete that has been corroded or chipped away with new concrete. The first issue that should be addressed in regards to concrete patches is whether they help maintain the strength of the structure. Mays et al. (1995) sought out to answer this question with the construction, repair, and testing of 1:2.5 scale models of reinforced concrete frame structures. The results of this study show that with suitable repair materials and modes of application, large volumes of concrete can be removed from a structure and then replaced, and the repaired section will behave structurally in a similar manner to the original section. The authors compared their test results to theoretical predictions to come up with this conclusion.

Even though concrete patches appear to be able to maintain the structural integrity of a structure, the question of their necessity in doing so arises. Raoof et al. (1997) conducted a series of tests on 44 simply supported damaged small-scale beams under single-point loading and 88 large-scale beams with a wider range of design parameters. Several noteworthy observations were made: (1) In beams that suffer from loss of concrete cover and the bond between the reinforcement and concrete, the percentage of main reinforcement and inclusion of nominal compression steel have a significant effect on the degree of loss of ultimate strength; (2) There is an apparent level of depth of removed concrete behind the main tensile reinforcement beyond which considerable losses of strength can occur; (3) Even without patch repair material, the ultimate load of beams suffering from loss of concrete cover and steel-concrete bond can remain the same as undamaged beams. This third observation is consistent with the conclusions of the testing of deteriorated bridge bents by Rowe (2001). Rowe concluded that the deterioration of the bridge bents did not affect their strength capacity because the main flexural reinforcement was not critically corroded.



### **1.2.2 Epoxy Injection**

A second method of repair is to inject epoxy into the cracks of a concrete section in order to seal the cracks and bond the two surfaces together. Abu-Tair et al. (1991) conducted tests on fourteen beams that had been previously tested under static loading and then epoxy resin injected. Beams were tested under one static and two cyclic load systems. Test results show that the epoxy injection restored the beams to their original strength and stiffnesses. Also, the prolonged cyclic load at very high stress levels did not cause the cracks to reopen. Basunbul et al. (1990) also tested epoxy injected concrete beams (along with three other methods of repair). The levels of damage to the beams studied varied from beam cracking at service loads to complete failure. The authors concluded that the epoxy injection method was shown to restore the strength and ductility of the beams for all levels of damage considered.

### **1.2.3 Carbon Fiber Reinforced Polymer**

Carbon fiber reinforced polymer (CFRP) wraps have been used to increase the capacity of concrete structures. Several researchers discuss the effectiveness of CFRP wraps: Arduini and Nanni (1997) tested shallow and deep reinforced concrete beams wrapped with CFRP for shear and flexural reinforcement. Of the two geometries tested, the strengthening was enhanced to a greater degree in the deep beams—with an increase of 44% equivalent reinforcement ratio, the ultimate capacity was increased 38%. Pantelides et al. (1999) also determined that CFRP wraps increased the strength of bridge bents tested with the superstructure still in place. One bent was tested “as is” while the second was retrofitted with CFRP wraps. Each column was wrapped in the plastic hinge region while the beam was wrapped in the joint region and at possible hinge regions. The strengthened bent sustained 35% higher stresses and 16% higher peak lateral load. In addition, displacement ductility was improved from 2.8 to 6.3.

While CFRP wraps can be used to strengthen reinforced concrete, there are several failure modes that can be of concern. Norris et al., (1997) tested precracked reinforced concrete beams wrapped with CFRP. Strength enhancement in the beams was measured at 20-100% when compared to the control beams. The CFRP reinforced beams did not fail in shear. Even though the beams were over-designed for flexure, the

longitudinal steel yielded and delamination at the midspan occurred before shear failure. The observation was that the peeling of the laminate was a continuing problem. Meier and Kaiser also observed the continuous peeling-off of the CFRP laminate during their experimental program. Other modes of failure observed were tensile failure of the CFRP laminate, concrete compressive failure, and sudden peel-off of the laminate due to shear cracks in the concrete. Chaallal et al. (1998) noted that there are two types of CFRP wrap peeling failure: (1) Debonding of the wrap from the concrete due to weak adhesive, and (2) ripping off of the concrete due to strong bonding of adhesive and concrete.

#### **1.2.4 Summary**

In summary, three methods for repairing damaged reinforced concrete have been researched—concrete patches, epoxy injection, and carbon fiber reinforced polymer. Research shows that depending on the amount of deterioration of the concrete and compression steel, concrete patches can be a viable method of restoring strength to a reinforced concrete structure. The structure may, however, be able to sustain approximately the same ultimate loads without any concrete patches even with loss of concrete cover and steel-concrete bond. In such cases the concrete patch would be merely cosmetic. Epoxy injection also appears to be a successful form of retrofitting concrete structures. Epoxy injection will also seal the cracks and keep the reinforcement from corroding further. Carbon fiber reinforced polymer wraps can significantly strengthen and stiffen concrete structures. The CFRP wrap may, however, fail in an undesirable manner thus limiting the strength potential of the CFRP/concrete composite.

## **2. Repair of Bents**

### **2.1 Repair Contractors and Specifications**

Bents 15N, 15S, 2N, 12N, 13S, and 13N were repaired. Some of them were repaired using just concrete patches and others were repaired by injecting their cracks with epoxy. After repaired, Bents 13S and 13N were also strengthened with Carbon Fiber Reinforced Polymer (CFRP) wraps.

Repair of the bents were accomplished using experienced workers. Gerber Construction Company, Inc. and Restruction Corporation were subcontracted to perform the work reported herein. The authors of this report supervised all the work. The UDOT Bridge Design and Operation department suggested the names of these two companies (Wheeler, 2000) because of their outstanding workmanship.

Bents were repaired using UDOT standard procedure methods. In addition to their outstanding workmanship, Gerber Construction Company, Inc. and Restruction Corporation are very familiar with UDOT specifications since they have worked in several UDOT projects. UDOT Standard Specifications for Road and Bridge Construction (Sections 03922, 03924 and 03935; see Appendix) were used for the work accomplished. Special provisions for composite wraps were followed for the strengthening of Bents 13S and 13N.

### **2.2 Concrete Patched Bents**

Bents 15N and 15S were repaired using concrete patches. Bent 15N was repaired using concrete manufactured by Sika, and Bent 15S was repaired using a polymer-based concrete from Elite Crete Systems. Appendix A contains copies of product literature and specifications of all products used. There were few preexistent cracks in Bent 15S, which were epoxy injected. The work was conducted by Gerber Construction under the supervision of the authors. Cover Crete, a local concrete resurfacing company and supplier of Elite Crete products, also participated in the repairing of bent 15S.

#### **2.2.1 Bent 15N**

Bent 15N was in fairly good condition compared to the other bents. Figure 1.2 shows the East side of the bent, which was the most damaged side. Figure 2.1 shows the west side as well as the underneath part of the cantilever, both in “fairly” good condition.

Most of the exposed rebar was at the fixed end of the bent. The fixed end of the bent was less critical because it was not going to be loaded directly. The load will be applied to the cantilever of the bent, and hence, the greatest stresses and strains would be in this portion of the bent.

The first step taken to repair Bent 15N was to chip away the unsound concrete around the exposed rebar with a jackhammer. Figure 2.2 shows the east side of the bent after the unsound concrete was removed and Figure 2.2a shows a detail of the longitudinal reinforcement. Figure 2.3 shows a schematic drawing of the exposed longitudinal reinforcement in the bent. Also shown is a top view of part of the bent. The percentage represents the approximate amount of longitudinal reinforcement remaining. The more that a section of rebar is exposed, the better the new concrete can encase the reinforcement. No more than about a quarter of an inch of space was between the exposed rebar and the “old” concrete. This 0.25 inch (6.35 mm) gap was determined, later on, not to be enough to make a good encasement of the “new” concrete around the reinforcement. After chipping away the unsound concrete, the bent was sand-blasted to remove any loose concrete and clean the reinforcement from any rust.

The bottom portions of the bent were coated with a bonding agent—Sika Armatec 110 EpoCem (see Appendix A). Forms were constructed around the bent, and the SikaRepair 222 concrete (see Appendix A) was poured. No aggregate was included in the concrete. Figure 2.4 shows the bent after its bottom portion had been patched. Due to weather conditions, a substantial length of time passed between the repairing of the bottom section and the rest of the bent. Slight rust formed on the exposed rebar during this time. Prior to repairing the rest of the bent, the rust was ground off the rebar.

The sides and top were coated with the same bonding agent, Sika Armatec 110 EpoCem; forms were constructed around the bent, and the Sika MonoTop 615 concrete was poured (see Appendix A). Figure 2.5 shows Bent 15N after it had been patched.

The bottom portions of Bent 15N were also repaired. The sides and top of the bent were repaired by the research team while assisted by Cover Crete. Repair materials were applied and used per specifications (Appendix A), and according to typical construction practices rather than in a laboratory setting.

### 2.2.2 Bent 15S

Bent 15S was repaired using a polymer-based concrete from Elite Crete systems (see Appendix A). Bent 15S was in a more deteriorated condition than Bent 15N. Figures 2.6a through 2.6e show the bent in place (East face), close-up of the East face, the East face and underside of the cantilever, close-up of the cantilever face and underside, and the West face and underside of the cantilever, respectively. The West face of the bent was in reasonable condition; however, the East face, cantilever face, and underside were significantly deteriorated. The shear reinforcement was exposed and corroded; some of the longitudinal reinforcement was exposed and corroded; and large pieces of concrete were missing. Figures 2.7 and 2.8 show the condition of the bent after the loose concrete had been chipped away using a jackhammer. Close inspection of Figure 2.8 shows that the entire cross-section of the shear reinforcement was exposed to allow the new concrete to fully enclose the rebar. The cross-section of the rebar on the underside of the bent, however, was only partially exposed, not allowing new concrete to encase the rebar. All of the exposed rebar was in fairly good condition, with respect to corrosion, with approximately 75-100% of the rebar cross-section remaining.

As with Bent 15N, the rust was taken off the rebar with a grinder before any concrete was poured. Figure 2.10 shows the condition of the rebar after grinding. After the rust was removed, the exposed areas of the bent were coated with a bonding agent—to help the new concrete bond with the old. Forms were constructed around the bottom of the bent and the concrete was poured. Figure 2.11 shows Bent 15S after the forms had been installed and the bonding agent had been applied.

When the forms were removed there were small pockets in the concrete as seen in Figure 2.12. To remedy this, new forms were built around the edge of the bent leaving a 1.5-inch (38 mm) gap between the surface of the bent and the form. Concrete was placed again to fill these small pockets. Figure 2.13 displays the newly built forms and Figure 2.14 shows the edge of the bent after the forms were removed. The 1.5-inch (38 mm) edge shown in Figure 2.14 was then chipped away using a chisel and grinder so that it was flush with the rest of the bent.

Finally, forms were constructed around the sides of the bent as shown in Figure 2.15, and concrete was placed down the sides and on top of the bent. The fully repaired bent is shown Figures 2.16-2.18.

After the bent was repaired with the concrete patch, some pre-existing cracks in the West face of the bent, as shown in Figure 2.19, were epoxy injected. A full description of the epoxy injection method is discussed in section 2.2.1 of this report.

## **2.3 Pre-Yielded Bents**

Bents 2N and 12N were tested previously (Rowe, 2001). Loading was applied to represent the forces caused by a low to moderate intensity earthquake. For reference, the tests conducted by Rowe will be defined as pre-yield tests. Bent 2N was a newly constructed bent built in 2000 where Bent 12N was an existing bent constructed in 1963. Bent 2N was repaired by injecting its cracks with epoxy and Bent 12N was repaired with a concrete patch only. Restruction Corporation carried out the repair of these two bents.

### **2.3.1 Bent 2N**

Bent 2N was in very good condition because of its new construction (Figures 2.20 and 2.21). The construction of this bent is discussed by Rowe (2001). The pre-yield test of Bent 2N caused several cracks to form; these cracks are highlighted in Figure 2.22. Besides these cracks, no other visible damage was caused by the pre-yield tests. The repair of Bent 2N consisted simply of epoxy injecting the cracks.

The first step in the epoxy injection method was to grind the concrete along the cracks. This was done to clean the surface along the cracks so that the cracks could be clearly seen. Next, small hollow tubes were inserted along the cracks about every 6 to 18 inches (152-457 mm). After the tubes were in place, the cracks were sealed so as to prevent leaking out of the epoxy at the surface during epoxy injection. The epoxy was then injected into the cracks through these hollow tubes. Figure 2.23 shows the hollow tubes and surface seal along a crack. Finally the epoxy was injected into the cracks through the tubes. Tyfo 103 Regular Injection Epoxy (see Appendix A for material specifications and properties) was used.

After the epoxy had time to cure, which took approximately two days, the surface seal and tubes were ground off so that there was a smooth surface on the bent. Figure 2.24 shows the array of plastic tubes along the cracks on the East face and Figure 2.25 shows the cracks after the grinding of the surface.

The epoxy injection was accomplished by an experienced crew as it would have been done in the field.

### **2.3.2 Bent 12N**

Bent 12N was an “old” bent and was therefore in worse condition than Bent 2N. Figures 2.26-2.28 show the condition of the bent before repair. As can be seen in Figures 2.27 and 2.28, the concrete on the underside of the sloped cantilever end was severely spalled to the point of exposing some of the reinforcement. The exposed rebar was partially corroded.

The first step taken to repair Bent 12N was to chip away the loose concrete with a jackhammer and fully expose the partially exposed rebar. Careful measures were taken to ensure that the rebar was exposed enough so that a human hand could be wrapped around the rebar. Previously developed cracks were to be epoxy injected, but after the old, loose concrete was chipped away the cracks were so small that they could not be located. The epoxy injection of the cracks was therefore not carried out on this bent. The decision not to epoxy inject this bent was justified by the fact that a scenario such as this could likely occur in the field and a bent that was initially intended to be injected with epoxy would not be due to the small size of the cracks.

Although these cracks were not epoxy injected, the bent was still patched with concrete. Before the bent was patched it was sand blasted to knock away loose concrete and remove the rust from the rebar. Forms were built around the bottom and sides of the bent and the concrete was poured. The concrete used to patch Bents 15N and 15S did not include coarse aggregate; however, the concrete used to patch Bent 12N did include coarse aggregate.

## **2.4 FRP Wrapped Bent 13S**

Bent 13S was repaired with shotcrete (a concrete patch) and strengthened with Carbon Fiber Reinforced Polymer (CFRP) wraps. Restruction Corporation carried out the repair of this bent.

Bent 13S was an old bent that was in poor condition. Figures 2.29a through 2.29d show the bent in place, the East face and underside of the cantilever, the face and underside of the cantilever, and the West face of the bent, respectively. There was a significant amount of concrete spalling as well as some corroded reinforcement.

Figures 2.29-2.31 show the bent after removing unsound concrete. There was a significant amount of reinforcement exposed on the East side of the bent with many of them considerably corroded. Figure 2.32 shows the amount of exposed reinforcement corrosion in the bent. The numbering shown represents the approximate percentage of remaining area. There were three vertical and one horizontal bars that were completely corroded (these bars are represented in Figure 2.32 by 0% rebar remaining). These bars were removed as shown in Figure 2.36 and not replaced.

As with the other bents, the first step in repairing Bent 13S was to chip away the concrete around the exposed rebar. As can be seen in Figures 2.33, careful consideration was taken to fully expose the reinforcement by chipping away approximately 1.5 inches (38 mm) of concrete around it. Figures 2.34-2.36 show the condition of the bent after the concrete was completely chipped away.

After the sections of rebar were fully exposed, the bent was cleaned by hydro-jetting. Figure 2.37 shows Bent 13S being hydro jetted. Hydro-jetting is the shooting of water at high pressure (approximately 25-35 ksi (173-242 MPa)), and performs various functions. First, it removes the unwanted rust from the rebar so that a good bond can be developed between the new concrete and the rebar. Second, hydro jetting knocks away any loose concrete and creates a rough surface so the old and new concretes can bond better. Figure 2.38 shows an untreated surface (bottom portion of the picture) and a treated surface (top portion of the picture).

The bent was patched with shotcrete using the dry-gun method. In this method of applying concrete to a surface the dry gunite cement and water are pumped through separate hoses where they meet and mix about 8 in before the end of the nozzle. The



result is a concrete mixture that is quite dry and sticks very easily to the surface to which it is being applied. It will even stick to surfaces overhead without falling off. It took several passes of the nozzle to adequately coat the bent and encase the rebar. Figures 2.39 and 2.40 show the shotcrete being applied and Figure 2.41 shows Bent 13S partially patched with shotcrete.

After the shotcrete cured for seven days, the bent was strengthened with Carbon Fiber Reinforced Polymer (CFRP) wraps. The CFRP used was Tyfo SCH-35 Composite system (see Appendix A).

Before the CFRP wraps were applied, the bent was sand blasted and washed. The bent was sand blasted to create a rough surface for the CFRP wraps to adhere to. The CFRP was applied in four layers, which formed a U-shape going from one face around the end of the cantilever to the other face. The first two layers were 24 in (610 mm) wide strips and the second two layers were 12 in (305 mm) wide strips. Figure 2.42 shows a drawing of the layer layout. The first step in applying the CFRP layers was to mix the two Tyfo S Epoxy components. This epoxy mixture was then used to coat the bent and each CFRP layer (Figure 2.43). Next, fumed silica was mixed with the epoxy to thicken it up and this mixture was applied to the bent. The first layer of CFRP was then applied (Figure 2.44) and anchored to the bent. It was anchored to the bent by drilling two holes approximately 4 inches (102 mm) deep with a 0.5 inch (12.7 mm) diameter into the bent at the end of the CFRP layer, inserting about 50 fiber strands into the hole and covering the hole and fiber strands with epoxy. To create an efficient anchor, the hole should have been completely filled with epoxy, but as will be discussed in Section 4 (Test Results) of this report, the hole was not completely filled with epoxy and did not properly anchor the CFRP wraps. Figure 2.45 shows two anchors were placed on each side of the bent for a total of four anchors. The remaining layers were applied in the same manner as the first layer, with each layer and the layer already on the bent being coated with epoxy before the layer was set in place. Figures 2.46 and 2.47 show the bents after all the CFRP layers were applied.

## **2.5 FRP Wrapped Bent 13N**

Bent 13N was also repaired with shotcrete (a concrete patch) and strengthened with Carbon Fiber Reinforced Polymer (CFRP) wraps. Restruction Corporation also carried out the repair of this bent.

Bent 13N was an old bent, but in better condition than bent 13S. Figures 2.48 through 2.55 show the condition of bent 13N prior to the repair. There was a significant amount of concrete spalling as well as some corroded reinforcement. Figure 2.56 shows the bent just prior of the fiber application and Figure 2.57 shows the reinforced bent. The procedure used to repair and reinforce Bent 13N was exactly the same as that of bent 13S.

The only difference between the fiber wrap reinforcement of bent 13S and bent 13N was the anchorage of the wraps. The anchorage of the wraps of bent 13S was accomplished with fiber strands placed in two holes near the end of the wraps (Figure 2.45). In addition to the same anchorage system of bent 13S, the anchorage of the wraps of bent 13N included three rows of three 0.5 in (12.7 mm) diameter steel bolts attached to 0.375 in (9.53 mm) steel plates (Figure 2.58 through Figure 2.62). The reason for this additional anchorage was the mode of failure of bent 13S, which will be discussed in Section 4.

### **3. Testing Methods**

#### **3.1 Test Frame**

A test frame was constructed to test the bents. A schematic drawing of the frame with a bent on its side is shown in Figure 3.1. The side position of the bent was necessary because of the position of the actuators. The bent, on its side, is laid next to a “strong” beam, which is also laid on its side. The frame clamps the portion of the bent opposite to the cantilever next to the strong beam with five “shear” beams on each side and four dywidag bars running through each shear beam. This allows the cantilever of the bent to be loaded while reacting against the strong beam. A concrete pad was constructed in the field as a spread footing to support the bent, shear beams, dywidags, and strong beam during testing. Figure 3.2 shows the concrete pad and Figure 3.3 shows the completed test frame with a bent in place. For a more detailed discussion of the test frame and its design, see Rowe (2001).

#### **3.2 Load Frame**

The load frame consists of the shear beam and anchoring system to the actuators. The first two tests, of Bents 15N and 15S, used the load frame shown in Figure 3.4. This frame consisted of a shear beam, which was connected to the actuators; four steel angles or “columns”, which were in place to keep the shear beam from moving perpendicular to the direction of loading; and a beam support, which was bolted into the concrete slab.

The shear beam rested on the base to allow it to slide in the direction of the applied loading. At the end of the second test, of Bent 15S, the load frame system failed—the bolts connecting the base to the concrete ripped out.

For the subsequent tests a new load frame was constructed. First the concrete was cut away around the old load frame and a hole about 40 in (1016 mm) deep was dug. Four steel square hollow tubes with a thickness of 0.25 in (6.35 mm) and cross-section height of 4 in (102 mm) were placed in the hole about 2 ft (610 mm) deep and tied together with No. 4 rebar. Holes were drilled into the old concrete and No. 4 dowels were placed into these holes to tie the old concrete with the new. Figures 3.5 and 3.6 show the steel tubes in place in the hole before the new 4000-psi (27.6 MPa) concrete was placed. Concrete was placed into the hole and steel angles were welded to the steel

tubes. A steel plate was greased and placed between the angles on the bottom and the shear beam so as to allow the shear beam to freely slide during testing.

The problems with the old load frame were due to the eccentricity in the loading. The shear beam would rotate about the direction of loading and the old frame couldn't resist that type of loading. The steel tubes in the new frame, however, resisted this eccentric load and transferred it adequately into the concrete. The new load frame preformed well during the remaining tests.

### **3.3 Instrumentation**

The measurements taken during the testing of the bents included displacement, and load. Linear Variable Differential Transformer (LVDT's) transducers and string potentiometers (string pots) were used to measure displacement, and load cells were used to measure load.

#### **3.3.1 LVDT's and String Pots**

Linear Variable Differential Transformer (LVDT's) transducers with a range of  $\pm 6$  in (152 mm) and string potentiometers (string pots) with a range of 10 in (254 mm) were used to measure displacement of the bents. Figure 3.7 shows the location of the LVDT's and string pots on the cantilever arm of the bent while Figure 3.8 shows their locations on the testing frame. Table 3.1 summarizes the location and range of each LVDT and string pot.

As shown in Figure 3.7, three LVDT's or string pots were mounted at each of four positions along the cantilever arm. These four positions were measured at approximate quarter points of the span, and at the tip of the cantilever. The positions were selected so that an average of the three measurements across a specific cross-section could be taken in order to get more accurate results at each point.

The LVDT's shown in Figure 3.8 were used to measure the rigid body motion of the bent with respect to the testing frame. LV8 and LV10 were both at the bent's point of rotation, one near the top face and one near the bottom face when the bent is laying on its side. LV7 was at an equal distance from the point of rotation as the point of loading—

approximately 7.5 ft (2.29 m). LV9 and SP9 were used to measure the movement of the loading frame and the strong beam, respectively.

### 3.3.2 Load Cells

Sensotec load cells with an accuracy of  $\pm 300$  lbs. (1.33 kN) were used to measure the load. Two load cells were used on the first (Bent 15N), fifth (Bent 13N) and sixth (Bent 13S) tests and one load cell was used on the second (Bent 15S), third (Bent 2N), and fourth (Bent 12N) tests. The load cell was positioned between the actuator and the bent as shown in Figure 3.9.

### 3.4 Data Acquisition

Data were collected with the MEGADAC 5414AC data acquisition system and an independent computer. The system has 128 strain gauge channels and 24 LVDT/string pot channels. All Bents used 17 LVDT/string pot channels.

### 3.5 Loading Protocol

Bents were loaded in a cyclic manner. Each cycle consisted of three pushes to a designated load or deflection. The first portion of each test was load controlled. Bents were loaded in five cycles to approximately a load of 400 kips (1779 kN) in 80 kip (356 kN) increments. Figure 3.10 and 3.11 show the loading protocol. After 400 kips (1779 kN), the test was conducted using a displacement controlled scheme. The deflection for each cycle was based on the estimated yield deflection. This approximate yield deflection was determined from the linear pre-yield slope with an estimated yield load of 600 kips (2669 kN):

$$\frac{320}{x_{320}} = \frac{600}{x_{yield}} \quad (2)$$

The bent was loaded to the approximate yield displacement, unloaded, then loaded to two times that displacement, unloaded, and then loaded to three times that displacement, and so on until failure. In both the load and deflection controlled portions of the test, each cycle consisted of three pushes to the designated level. On the third push

the load was maintained for about 10 minutes while the bent was marked for cracks and notes where taken.

## **4. Test Results**

Five bents were tested to failure. Bents 15N and 15S were repaired with concrete patches and tested. Bents 2N and 12N had been tested to their yield loads previously before they were repaired and tested to failure. Bent 13S was repaired with a concrete patch and carbon fiber reinforced plastic (CFRP) wraps and tested.

### **4.1 Monitoring of Test Frame**

The test frame, after being repaired, performed well throughout the duration of the testing. There were only a few concerns dealing with rigid body motion of the bent. It was impossible to place the bent flush against the top concrete portion of the test frame on the fixed end; so steel shims were placed between the bent and the test frame before pre-stressing the dywidag bars. Steel shims were also placed between the strong beam and the column portion of the bent. The location of the steel shims is shown in Figure 4.1. These shims caused stress concentrations in the column portion of the bent, which caused the concrete to crack as shown in Figure 4.2. Because the bent was not completely fixed, it rotated and displaced slightly. The direction of rotation and translation is shown in Figure 4.3. These two forms of rigid body motion were accounted for in the analysis and reduction of data.

### **4.2 Data Reduction**

Data for each test were collected at a rate of one data point per second. Each test lasted several hours amounting to approximately 7500 data points. The data were reduced by taking an average of every four data points. All tables and graphs were produced from the reduced data.

The three displacement measurements, taken in each of the four locations of the cross-section of the cantilever arm (see Figure 3.7), were averaged to determine an average displacement for each location.

Rigid body motion was accounted for by taking displacement readings at the locations for LV7, LV8 and LV10 (see Figure 3.8). The measurement at LV8 and LV10 were averaged, and that average and the value for LV7 were subtracted from the displacement readings of the cantilever arm.

### **4.3 Concrete Patched Bents**

Bents 15N and 15S were the first two bents tested. These bents were patched with concrete as discussed in Section 2.1. Both bents were tested using the original loading frame (Rowe, 2001). Bent 15N however was tested using two hydraulic jacks where Bent 15S was tested using only one. This difference was considered inconsequential to the results of the tests because the capacity of each bent was smaller than the capacity of one jack. Originally it was not known whether the capacity of the bents would exceed the capacity of only one jack, so two jacks were used. After testing Bent 15N the loading capacity of only one jack was determined to be sufficient to take the bents to failure.

#### **4.3.1 Bent 15N**

Bent 15N was the first bent tested. Table 4.1 summarizes the peak loads and corresponding deflections for each push of each cycle. The peak load was 637 kips (2834 kN). The bent was pushed to a maximum deflection of 3.59 in (91.2 mm).

Peak loads are shown graphically in Figure 4.4. This graph shows that the initial stiffness of each push are very similar up to the yield point. Beyond the yield point the secondary stiffness values still correspond closely to each other, but the peak loads for the second and third push are approximately 30-50 kips (133-222 kN) lower than that of the first push.

The original and corrected load vs. deflection curves are shown in Figures 4.5 and 4.6 respectively. The corrected curve in Figure 4.6 shows that the rigid body motion of Bent 15N was relatively small. These curves show that the bent yielded around 605 kips (2691 kN). Beyond the yield point the permanent deflection is shown as the distance between the loading slope of one cycle and the unloading slope of the following cycle.

Bent 15N didn't show any sign of cracking (except for the shrinkage cracks which were visible before testing started) until the third cycle, at a peak load of approximately 365 kips (1624 kN). The hairline cracks started along the reentrant corners of the pedestals, shown in Figure 4.7, at the "top" of the cross-section through the bent, shown in Figure 4.8. The cracking at the reentrant corners was due to the stress concentrations at this interface, while the cracks at the "top" are due to flexure.



On the fourth cycle, at a peak load of approximately 405 kips (1802 kN), long cracks began to develop across the cross-section as seen in Figure 4.9. These cracks propagated from the top of the bent towards the lower corner where the cantilever of the bent meets the column. The direction of crack propagation is illustrated in Figure 4.10. These long cracks went through a little more than half the cross-section. On the top surface of the bent many cracks developed which were determined to be the opening of small shrinkage cracks. These cracks can be seen in Figure 4.11.

The bent yielded on the fifth cycle at a load of approximately 605 kips (2691 kN). The deflection at this peak load was approximately 0.62 in (15.7 mm). No new large cracks formed, but the existing long cracks continued to elongate as shown in Figure 4.12. This elongation of the cracks continued in the sixth cycle, which reached a peak load for the bent of 637 kips (2834 kN). This load caused a permanent deflection of about 1.34 in (34.04 mm) and the cracks, shown in Figure 4.13, began to widen noticeably.

On the seventh cycle, at a peak load of 625 kips (2780 kN), the cracks continued to widen, and many new, short cracks formed at the top of the cross-section as shown in Figure 4.14. These short, well distributed cracks were an indication of yielding in the reinforcement. The total permanent deflection after this cycle was about 2.00 in (50.8 mm). The concrete in the compression zone of the bent (at the intersection between the cantilever and column) began to crush and continued to do so until failure. Figure 4.15 displays the crushing in the compression zone after failure of the bent.

Testing was halted after the first push of the eighth cycle to avoid damage to the instrumentation and testing frame. The swivel head between the bent and the loading cell could not rotate any further and was shearing off in bits. The bent had also reached its maximum load as evidenced by the “flatness” of the load-deflection curve (see Figure 4.5). Figure 4.16 displays the cracks after failure on the first push of the eighth cycle. Many cracks ranged in width from 0.20 to 0.50 in (5.08-12.7 mm) as seen in Figures 4.17 and 4.18. This last push before failure reached a peak load of 630 kips (2802 kN) which is slightly lower than the maximum load of 637 kips (2834 kN) obtained on the sixth cycle. The deflection of the bent on this cycle was 3.59 in (91.19 mm). After unloading

the bent there was a permanent deflection of about 2.55 in (64.77 mm) Pieces of the concrete patch on top of the bent fell off in small blocks.

#### **4.3.2 Bent 15S**

Bent 15S was the second bent tested and the last one tested with the old loading frame. Before the test started numerous shrinkage cracks were noted on the top of the bent as seen in Figure 4.19.

The peak loads and corresponding deflections for each push of each cycle are summarized in Table 4.2. Peak loads are represented graphically in Figure 4.20. Figure 4.20 shows that Bent 15S followed the same trend in stiffness as Bent 15N, where the stiffnesses of each push are very similar up to the yield point. Beyond the yield point the stiffnesses of the second and third push still correspond closely to each other, but the peak loads are lower than the first push.

The original and corrected for rigid body motion load vs. deflection curves are displayed in Figures 4.21 and 4.22 respectively. Figure 4.22 was also corrected for several erroneous data points, which can be seen in Figure 4.21. These erroneous data points were most likely caused by movement of the loading frame which would cause the bent and instrumentation to shake and vibrate, thus resulting in inaccurate displacement measurements. Also, comparisons between the original and connected data show that neither stiffness nor load was compromised by the elimination of these erroneous data points. By comparing these graphs it can be seen that the rigid body motion in Bent 15S was slightly larger than that in Bent 15N. The larger rigid body motion may be attributed to problems at the fixed end of the bent. During the third loading cycle the steel beams on the fixed end of the bent were making a popping noise. The noise was indicative of movement of the shear beams, but it couldn't be determined exactly which beam or at what point the noise and movement was coming from. Most likely what happened was that some shear beams were fixed against the base of the testing frame instead of being fixed against the bent being tested. This would allow the supposedly fixed end of the bent to move. The moving bent could then press against the shear beams unsymmetrically causing slippage between the bent and shear beam. This slippage would cause the beams to "pop" back thus creating the popping noise.

On the fourth cycle, at a peak load of 363 kips (1615 kN), the first hairline cracks became visible as shown in Figure 4.23. During the fourth cycle a new crack formed between strain gages #1 and #5 as shown in Figure 4.23.

No new cracks appeared on the fifth cycle, at a peak load of approximately 404 kips (1797 kN), but cracks continued to grow as shown in Figure 4.24. On the sixth cycle, at a peak load of 598 kips (2660 kN), previous cracks continued to grow, and several new cracks formed as shown in Figure 4.25. The bent appeared to yield somewhere between the sixth cycle and the beginning of the seventh cycle at about 601 kips (2673 kN). This yielding is apparent from examination of Figure 4.22. The deflection at the yield point was approximately 0.64 in (16.26 mm).

Several noteworthy events occurred on the seventh cycle, which reached a peak load for the cycle and the bent of 635 kips (2825 kN) and caused a permanent deflection of about 1.12 in (28.45 mm). First, the cracks which developed previously grew significantly in length and width. These cracks are shown in Figure 4.26 and followed the propagation direction shown in Figure 4.10. The larger cracks grew to widths of between 0.25 to 0.375 in (6.35-9.53 mm) as seen in Figures 4.27 and 4.28. Second, as shown in Figure 4.29, large cracks formed along the entire length between the interface of the old and new, patched concrete. Figure 4.30 shows these cracks on the bottom face of the cantilever. The width of these cracks on the top face ranged from 0.25 to 0.375 in (6.35-9.53 mm) (Figures 4.31 and 4.32) and on the bottom face got as large as 0.50 in (12.7 mm) (Figure 4.33). These cracks most likely developed because of the weak bond between the old and the new concrete. This bent was patched with the Elite Crete system.

On the first push of the eighth cycle, which reached a peak load of 597 kips (2656 kN), the cracks that formed along the interface between the old and the new concrete started to widen substantially. These large cracks can be seen in Figure 4.34. The largest of these cracks were at least 1 in (25.4 mm) in width and daylight could be seen when looking down the crack to the bottom. The whole bottom face was in jeopardy of falling off, so all instruments, except for the three string pots on the far end (closest to where the load was being applied), were removed to protect them from being damaged.

The second push of the eighth cycle reached a load of 599 kips (2664 kN) and a deflection of 2.95 in (74.93 mm) when the load frame failed. Throughout the tests conducted using this load frame, the eccentricity of the load would cause the frame to slightly rotate perpendicular to the direction of loading. Figure 4.35 shows the loads on the frame and its direction of rotation. The steel beam to which the actuators were connected would press against the frame causing it to rotate. Slippage would occur at the point of contact between the steel beam and the frame allowing the frame to return to its original position. When the load frame failed it was rotating; when it slipped back to its original position it released enough uplift force that the bolts holding the frame in the concrete pulled out. The concrete around the bolts was already cracked before the failure occurred. The failed load frame is shown in Figures 4.36 and 4.37. When the load frame failed the collision of the dywidag bars against the bent caused the concrete patch to fall off completely (Figure 4.38). Figures 4.39 and 4.40 show that the failed surface was clearly between the patched concrete and the old concrete surface as evidenced by the whitish surface, which was the bonding agent applied before the bent was repaired with the concrete patch. Failure of the concrete patch was already eminent due to the large cracks along the interface of the old and new concrete. The collision of the dywidag bars only accelerated that failure. The bent reached a maximum deflection of 2.95 in (75 mm) and had an approximate permanent deflection of 2.4 in (61 mm).

#### **4.4 Pre-Yielded Bents**

Bents 2N and 12N were the third and fourth bents tested. Bent 2N was a newly constructed bent while Bent 12N was old. Both bents were previously loaded to their approximate yield points (Rowe, 2001). Bent 2N was repaired using epoxy injection and Bent 12N was repaired using a concrete patch. The repair of these bents is discussed in Section 2.2. Both bents were tested using the newly constructed load frame, discussed in Section 3.2.

#### 4.4.1 Bent 2N

Bent 2N was the third bent tested. It reached a maximum load of 671 kips (2985 kN) and was pushed to a deflection of 5.84 in (148.34 mm). Table 4.3 summarizes the peak loads and corresponding deflections for each push of each cycle.

Peak loads are represented graphically in Figure 4.41. It is evident from Figure 4.41 that the stiffnesses of each push up to the yield point are very similar. After the yield point the secondary stiffnesses of each push are also very similar, but the peak loads of the second and third push are slightly lower than the first push by about 30 to 40 kips (133-178 kN).

Figures 4.42 and 4.43 show the original and corrected for rigid body motion load vs. deflection curves for Bent 2N. In Figure 4.44 the load vs. deflection curve for the test conducted by Rowe (2001) is shown superimposed onto the full response of the bent. A comparison of these two curves shows that after being pre-yielded and repaired, Bent 2N is slightly less stiff than it was originally and that the load applied by Rowe (2001) was slightly less than the actual yield load.

Cracks started to form on the second cycle at a peak load of 171 kips (761 kN). This was much earlier than the other bents tested, which usually began to crack around 360 kips (1601 kN). The most apparent cracks were on the top of the bent and were opening where the previous cracks had been injected with epoxy. Some of these cracks extended into the cross-section of the bent as seen in Figure 4.45, even at this early stage of loading. Not many new cracks formed on the third, fourth, or fifth cycles at peak loads of 244 (1085), 366 (1628), and 407 kips (1810 kN), respectively. The pre-existing cracks just continued to widen and lengthen. By comparing the cracks illustrated in Figures 4.46 and 4.47 with the epoxy-injected cracks in Figure 4.48 it is evident that the cracks developed during this test are simply the opening of the epoxy injected cracks.

On the sixth cycle Bent 2N yielded at about 585 kips (2602 kN), which was very close to the peak load of 588 kips (2616 kN). The deflection at the yield point was 0.83 in (21.08 mm). No new cracks formed on the sixth cycle as evidenced in Figure 4.49, but the existent cracks continued to widen.

On the seventh cycle, at a peak load of 632 kips (2811 kN), several large, new cracks developed across the entire length of the top of the bent as shown in Figure 4.50.

These cracks didn't extend into the top face (cross-section) until the eighth and ninth cycles. Also the old cracks continued to lengthen as shown in Figure 4.51. Furthermore, the concrete in the compression zone of the bent began to crush and spall as shown in Figure 4.52.

On the eighth cycle, at a peak load of 657 kips (2922 kN), the new cracks formed on cycle seven began to lengthen significantly toward the compression zone. Figure 4.53 shows the cracks observed during this cycle. On the ninth cycle the bent reached its maximum peak load of 671 kips (2985 kN). Some of the cracks lengthened into the column portion of the bent as seen in Figure 4.54. After the ninth cycle the bent had a permanent deflection of about 2.6 in (66 mm).

Bent 2N failed on the first push of the tenth cycle, which reached a peak load of 663 kips (2949 kN). The bent failed at a deflection of 5.84 in (148 mm). Figures 4.55 and 4.56 show the cracks in the cross-section and on top of the bent after failure, respectively. Cracks ranged in size from approximately 0.375 to 0.75 in (10 to 19 mm) as shown Figures 4.57-4.59.

The new load frame performed significantly better than the old load frame during this test. The beam still wanted to rotate due to the eccentricity in the loading, but the steel tube columns were able to resist the loads without any significant movement.

#### **4.4.2 Bent 12N**

Bent 12N was the fourth bent tested. It had a maximum peak load of 761 kips (3385 kN) and was loaded to a deflection of 8.28 in (210 mm). Table 4.4 shows the peak loads and corresponding deflections for each push of each cycle. Peak loads are represented graphically in Figure 4.60. This figure shows that Bent 12N followed the same trend in stiffness as Bent 2N where the stiffnesses of each push are very similar up to the yield point. Beyond the yield point the secondary stiffnesses of the second and third push still correspond closely to each other, but the peak loads are lower than the first push.

The original and corrected load vs. deflection curves are displayed in Figures 4.61 and 4.62 respectively. The corrected curve in Figure 4.62 shows that the rigid body motion of Bent 12N was relatively small. These curves show that the bent yielded

around 628 kips (2793 kN) at a deflection of 1.76 in (45 mm). Figure 4.63 shows a comparison of the load vs. deflection curves for the pre-yield test and the test to failure for Bent 12N. As apparent from this figure, the bent was stiffer on the pre-yield test than it was when taken to failure. Also, the actual yield load was slightly greater.

Cracks began to form along the entire length of the top of the bent on the third cycle at a peak load of 247 kips (1099 kN). These cracks ran into the cross-section of the bent slightly, as can be seen in Figure 4.64. These cracks are most likely the cracks that developed when the bent was tested previously. A crack also appeared at the base of the bent's column at the edge of the shim as shown in Figure 4.65.

On the fourth cycle, at a peak load of 327 kips (1455 kN), the cracks extended about half way into the cross-section. The crack length growth is evident in Figure 4.66. The concrete at the column base shown in Figure 4.65 continued to crack and crush significantly.

On the fifth and sixth cycles, at peak loads of 410 (1824) and 522 kips (2322 kN) respectively, a few new cracks developed, and the existing cracks continued to lengthen slightly toward the interaction of the cantilever of the bent and the column. These cracks are shown in Figures 4.67 and 4.68. The crack growth propagated in the same direction as the cracks in the other bents tested (see Figure 4.7). On the sixth cycle a large piece of concrete at the column base fell off. This piece was set next to the spot where it fell out and is shown in Figure 4.69. This failure was due to the stress concentrations at the shim. Instead of the bent having an evenly distributed area of contact with the strong steel beam for the load to be resisted, the load was resisted at the concentrated area where the shim was in contact with the bent. This caused a stress concentration at this location, which caused cracks to develop in the bent at the edges of the shim. As the load increased, these cracks continued to grow and the concrete in this area was crushed and failed.

Bent 12N yielded on the seventh cycle at a load of approximately 628 kips (2793 kN). The peak load for this cycle was 653 kips (2905 kN). On the seventh, eighth, and ninth cycles many new cracks appeared in the cross-section as the old cracks widened. The cracks on these cycles are shown in Figures 4.70-4.72 respectively. The concrete in the compression zone of the bent began to crush as shown in Figure 4.73. The peak loads on the eighth and ninth cycles were 676 (3007) and 678 kips (3016 kN) respectively.

This portion of the loading cycle was controlled by deflection, so during these cycles the bent was deflecting about 2 in (51 mm) without any increase in load.

The bent was then taken to failure on the first push of the tenth cycle. The load increased unexpectedly to about 761 kips (3385 kN). Many new, small cracks developed in-between the existing cracks. The well distributed crack pattern can be seen in Figure 4.73. The concrete in the compression zone of the bent crushed dramatically and a large piece nearly fell off completely. This dramatic crushing was due to the bent being deflected 8.28 in (210 mm), which was substantially larger than the deflection of any of the other bents tested to date. The crushing of the compression zone can be seen in Figures 4.74 and 4.75. Figure 4.76 shows a rather large crack along the main tension reinforcement. This was an old crack that existed even before any testing (Rowe, 2001). Figure 4.77 shows this crack before any testing. Larger cracks through the cross-section ranged in width from approximately 0.25 to 1.00 in (6 to 25 mm) as shown in Figures 4.78 and 4.79, respectively. At the reentrant corner on top of the bent the cracks were 0.75 in (19 mm) in width as shown in Figure 4.80. Figure 4.81 shows the overall permanent displacement of Bent 12N at failure.

#### **4.5 CFRP Wrapped Bent 13S**

Bent 13S was the fifth tested. It had a maximum peak load of 762 kips (3390 kN) and deflected only 1.20 in (30.48 mm) before failure. Table 4.5 shows the peak loads and corresponding deflections for each push of each cycle. Peak loads are represented graphically in Figure 4.82. It is apparent that there is not a well-defined yield point. The bent strengthened with CFRP composite performed more like a “brittle” system where the system never really yielded in the classic “sense”, but rather reached an ultimate load and failed. The original and corrected load vs. deflection curves shown in Figures 4.83 and 4.84, respectively, are further evidence of the brittle nature of the system. If a yield point was chosen, from Figure 4.84 it would be around 500 kips (2224 kN), which shows a slight change in stiffness.

The first three loading cycles established that the bent was going to be much stiffer than previous bents tested. At a load of 300 kips (1334 kN) the bent had a displacement of only about 0.14 in (3.6 mm). The loading protocol was therefore



changed: the bent was loaded to 400 (1779), 500 (2224), and 650 kips (2891 kN) instead of 320 (1423) and 400 kips (1779 kN) before continuing the test using a displacement control scheme (see Section 3.5 for a discussion on the loading protocol.) On the fourth cycle new cracks formed in the reentrant corners on the top of the bent, but no cracks formed anywhere else on the bent. There were several shrinkage cracks visible before testing began, but these cracks did not appear to widen or affect the test throughout its duration. These shrinkage cracks are shown in white in the corresponding figures.

On the fifth cycle at a peak load of 505 kips (2246 kN) and deflection of 0.20 in (5.1 mm), one crack formed across the entire width of the top of the bent. This crack can be seen in Figure 4.85. The cracks in the reentrant corners are also illustrated in this figure. On the sixth cycle at a peak load of 703 kips (3127 kN) a few cracks appeared in the cross section of the bent just below the CFRP layers. These new cracks are shown in Figure 4.86. These cracks probably formed on an earlier loading cycle but couldn't be seen because the CFRP covered them. On the sixth cycle these cracks lengthened and widened to where they were visible.

The cracks that were seen on the sixth cycle continued to lengthen on the seventh cycle at a peak load of 762 kips (3390 kN) and are shown in Figure 4.87. This load was reached on the first push of the seventh cycle and was also the ultimate load. Also on the seventh cycle a portion of the CFRP composite debonded from the concrete. This occurred in the area next to the middle pedestal as shown in Figure 4.88. Figure 4.89 shows a close up of this section where a definite gap exists between the CFRP and the concrete. The debonded region is shown in Figure 4.90 as the area between the two dashed black lines on the CFRP composite. There was about 40 in (1016 mm) of CFRP to the right of the debonded region, toward the fixed end, that was still bonded to the bent.

On the first push of the eighth cycle, at a load of 744 kips (3309 kN), the CFRP composite failed by completely debonding as shown in Figures 4.91-4.93. Apparently, debonding occurred first on the downward face of the bent. This was noticed by a loud noise heard just before complete failure. The noise came from the downward face of the bent. When the debonding occurred at the downward face, the force transferred to the CFRP in the top face of the bent. Since the force was too much for only one face, the

CFRP completely debonded. The cracks in the cross section of the bent lengthened significantly and two new cracks formed. These new cracks are the two cracks on the right most side of Figure 4.94. Figure 4.95 shows a new crack that developed on the top of the bent in the middle of the middle pedestal. Figure 4.96 shows that the debonding went as far as the right side of the middle pedestal. The crack width at the bottom of the reentrant corner on the middle pedestal was about 0.375 in (9.5 mm) as shown in Figure 4.97. After the debonding occurred the testing was stopped so as to prevent any possible damage to the instrumentation. Even though the bent could probably sustain more loading cycles, after the failure of the CFRP, the bent would be expected to behave in a similar manner to the other concrete patched bents and not be able to carry a greater load than the ultimate load of 762 kips (3390 kN). Unlike the compression zone of the other bents, the concrete in the compression zone of Bent 13S did not crush as shown in Figure 4.98.

Inspection of the anchoring system of the CFRP to the concrete (see Figure 2.45) revealed that the fiber strands which were to act as anchors were dry, and not coated with epoxy. For the anchoring system to work, the hole in the concrete and CFRP must be filled with epoxy, the strands pushed into the hole, and the hole covered with more epoxy. This creates an “epoxy-reinforced bolt”. On Bent 13S it is evident that this anchoring system did not occur. The hole was not filled with epoxy. Apparently, the fiber strands were pushed into the hole and the hole was covered with epoxy, but this was not sufficient to create the epoxy-reinforced bolt. It could be that if the anchoring system was prepared correctly, Bent 13S could have sustained slightly larger loads before failure. Due to the initial debonding that occurred at the pedestal location, the epoxy-reinforced bolts could have simply sheared-off when the CFRP completely debonded and not add any capacity to the bent.

#### **4.6 CFRP Wrapped Bent 13N**

Bent 13N was the last bent to be tested. It had a maximum peak load of 882 kips (3924 kN) and deflected only 0.92 in (23 mm) before failure. Table 4.6 shows the peak loads and corresponding deflections for each push of each cycle. Data for the first three cycles were collected but not saved properly making them inaccessible. Based on the

results from bent 13S and the results from bent 13N, bent 13N can be assumed to behave linearly during the first six cycles.

Peak loads are represented graphically in Figure 4.99. Unlike bent 13S, bent 13N behaved in a ductile manner even though there is not a well-defined yield point. The original and corrected load vs. deflection curves shown in Figures 4.100 and 4.101, respectively, are further evidence of the ductile behavior of the bent. Similar to the response of bent 13S, the first four loading cycles established that bent 13N was going to be much stiffer than previous bents tested. At a load of 392 kips (1744 kN) the bent had a displacement of only about 0.15 in (3.81 mm). The loading protocol, however, was not changed as it was during testing of bent 13S because it was expected that bent 13N would be more ductile than bent 13S.

Figures 4.101 and 4.102 show shrinkage cracks on bent 13N. These cracks were marked to distinguish between existing and new cracks. In the opinion of the authors, the existence of these cracks did not influence the response of the bent. Figure 4.103 shows the condition of the bent after the third loading cycle. Small cracks started to appear on the top of the bent. No new cracks were visible on the side of the bent after the third loading cycle.

On the fourth cycle a new vertical and a new horizontal crack formed on the top of the bent. These cracks are shown in the right side of Figure 4.104. The vertical crack similar to previously observed vertical cracks is due to bending. The horizontal crack may be due to localized bond failure along the flexural reinforcement. The propagation of this horizontal crack may be an indication of bond failure. The cracks that were visible after the third cycle became slightly widened after the fourth cycle.

On the fifth cycle at a peak load of 501 kips (2229 kN) and deflection of 0.22 in (5.6 mm), one crack appeared at the end of the FRP wraps (Figure 4.105). The authors believe this is the same crack that appeared near the beginning of the anchoring steel system (Figure 4.106). Because the crack is under the FRP wrap, its path could not be determined exactly. Three new cracks also appeared on the face of the bent (Figure 4.107). The exactly path of these cracks toward the top of the bent could not be traced since they were also covered by the FRP wrap. New cracks also appeared on the top of

the bent (Figure 4.108). The horizontal crack that appeared at the end of the fourth cycle did no propagate any farther.

On the sixth cycle at a peak load of 608 kips (2706 kN) the crack at the end of the FRP wrap widened (Figure 4.109). The cracks on the cantilever also widened and propagated toward the compression zone (Figure 4.110).

On the seventh cycle at a peak load of 761 kips (3386 kN) the crack at the end of the of the FRP wraps (Figures 4.105 and 4.109) connected to the crack near the beginning of the anchoring steel system (Figure 4.106) as shown in Figure 4.111. The FRP wrap started to debond at its ends (Figure 4.111). The cracks at the cantilever and the top of the bent widened. Two new cracks appeared: one on the cantilever (Figure 4.112) and one at the top (Figure 4.113). On the eighth cycle cracks became more visible because of widening (Figure 4.114) and because of propagation (Figure 4.115).

Cracks previously observed continued to lengthen and widen on the ninth cycle at a peak load of 873 kips (3885 kN). The crack on the top of the bent near the pedestal became very large (Figure 4.116) and the cracks on the face of the cantilever started to converge to the main compression zone near the intersection of the column and the cantilever (Figure 4.117). As seen in Figures 4.116 and 4.117 the cracks are well distributed along the tension side of the bent indicating that the bent is failing in flexure. As shown in Figures 4.118 and 4.119, the crack that started at the end of the FRP wrap continued around the steel anchoring system and propagated toward the main compression focus point. The steel anchoring system performed as intended and designed by keeping the ends of the FRP wraps anchored to the concrete even when the FRP wrap started to debond and significantly “pry up” as shown in Figures 4.119 and 4.120. If the anchoring system was not effective, the bent most likely would have failed already.

Cracks propagated and widened significantly during the tenth cycle at a peak load of 882 kips (3925 kN). Also, the FRP wrap debonded and buckled as shown in Figure 4.121. During this cycle only the anchoring bolts appear to be effective by transferring the load through shear from the FRP wraps to the concrete since the entire FRP wrap appears to have completely debonded (Figure 4.122). Cracks were very wide near the pedestal (Figures 4.123 and 4.124). Testing was halted after the tenth cycle to prevent

damage to the instrumentation. Figure 4.125 shows the condition of the FRP wrap after testing. An inspection of the steel anchoring system indicated that most of the steel bolts had sheared off (Figure 4.126).

## **5. Interpretation of Results**

### **5.1 Yield Load**

The yield loads for each bent were determined from their load versus deflection curves as the load where there was a sharp change in stiffness. These yield load values are summarized for each bent in Table 5.1. The results from the bents tested by Rowe (2001) are also included in this table (in the gray rows) for comparison purposes. Figures 5.1 and 5.2 show a comparison of the load vs. deflection graphs for all the bents.

The pre-yielded bents (2N and 12N) yielded at 585 (2602) and 628 kips (2793 kN), respectively. These compare almost exactly to the yield loads of 588 (2616) and 625 kips (2780 kN) for Bents 1N and 12S. Bent 1N was a new bent tested to failure and Bent 12S was an old bent tested to failure. The pre-yield test did not load the bents past the elastic range and the epoxy injection on Bent 2N and the patch on Bent 12N were sufficient forms of repair to maintain the yield capacity of the bents. This was expected since the yield load is a function of the reinforcement and the reinforcement was not changed. The yield loads for the new bents (1N and 2N) and the old bents (12N and 12S) however differ by about 40 kips (178 kN). Rowe (2001) attributed this difference in yield to the difference in rebar used in the new bents (1N and 2N). Rowe adjusted the load of the new bent by using an equivalent reinforcement area resulting in a yield load of 619 kips (2753 kN) which is similar to the 625 kips (2780 kN) yield load for Bent 12S. Bent 2N can be adjusted using the same procedure in which case the yield load would be around 620 kips (2758 kN). Therefore bents 1N, 2N, 12S, and 12N all yielded around 620 kips (2758 kN). The patched concrete bents (15N and 15S) yielded closer to 600 kips (2669 kN), which is still in the same range as the other bents. Bent 13S, however, yielded around 500 kips (2224 kN). This was most likely due to the significant corrosion to the reinforcement in the bent. Figure 2.32 shows that in some places the reinforcement was corroded leaving as little as 50% of the original rebar cross-section area.

### **5.2 Strength**

The ultimate load for each bent was determined from the load versus deflection curves for each respective bent and was defined as the maximum load resisted by the

bent. The ultimate loads of each bent are summarized in Table 5.1. Table 5.1 also presents the displacement of each bent at the ultimate load.

The maximum load for the epoxy injected bent (2N) is 671 kips (2985 kN) which represents a reduction in strength of 5.5 percent compared to the ultimate load of 708 kips (3149 kN) for Bent 1N. This decrease in strength seems to show that the epoxy injection did not sufficiently fill all the pre-existing cracks and restore the bent's original strength capacity. Bent 12N, the other pre-yielded bent, however, had an ultimate load of 761 kips (3385 kN) which is an increase in strength of 6.8 percent compared to the maximum measured load of 709 kips (3154 kN) for Bent 12S, which was tested straight to failure. This increase can be attributed to strain hardening.

Bents 15N and 15S, which were patched with concrete, had ultimate loads of 637 (2834) and 635 kips (2825 kN). This is about a 10 percent decrease compared to Bent 12S, which was in similar pre-repair condition, but had no repair work done to it when it was tested. Differences in the strength of the concrete and location and condition of the reinforcement when the bents were first constructed may be the cause of this decrease in strength. Bent 13S, which was repaired with a shotcrete patch and CFRP, reached an ultimate load of 762 kips (3390 kN). This was the highest load obtained of any of the bents (although very close to that of Bent 12N). It is believed that this bent could have sustained even higher loads if the debonding had not occurred and the anchoring system for the development length of the CFRP to the concrete had been properly installed and considered.

### **5.3 Stiffness**

The initial stiffness of each bent was calculated from the 'stiffness of the first push' for each bent. The initial part of each of these graphs was linear. The slope of the linear portion of these graphs was defined as the initial stiffness. The stiffness values of each bent are summarized in Table 5.1.

Bent 2N had an initial stiffness of approximately 650 kips/in (114 kN/mm), which represents degradation in stiffness of about 26 percent from its original stiffness of 880 kips/in (154 kN/mm). Bent 12N also decreased in stiffness from 840 (147) to 600 kips/in (105 kN/mm), or about 29 percent. Bents 15N and 15S, however, had surprisingly high

stiffnesses, 1350 (236) and 1040 kips/in (182 kN/mm), respectively. The increases are approximately 40 and 23 percent higher compared to the stiffness of Bent 12S. This raises an interesting point in regards to the patched bents.

Bent 13S, the CFRP wrapped bent, had an initial stiffness of approximately 2100 kips/in (368 kN/mm), which is more than twice the stiffness of most of the other bents. The overall stiffness of Bent 13S was also greater than any of the other bents. Bent 13S deflected only 0.65 in (16.51 mm) at an ultimate load of 762 kips (3390 kN). The next closest bent in regards to stiffness was Bent 15S, which deflected 1.70 in (43.18 mm) at an ultimate load of only 635 kips (2825 kN). So Bent 13S deflected nearly a third of Bent 15S at a load of 130 kips (578 kN) greater. This great increase in strength can be attributed to the added CFRP reinforcement.

#### **5.4 Cracking**

The bents tested all began cracking on different cycles. The concrete patched Bents 15N and 15S began cracking in their reentrant corners on the first push to 360 kips (1601 kN). The CFRP wrapped Bent 13S didn't begin to crack until the first push to 400 kips (1779 kN). These cracks also formed in the reentrant corners of the bent. The epoxy injected Bent 2N began cracking on the first push to 170 kips (756 kN) and the other pre-yielded Bent 12N began cracking at 250 kips (1112 kN). The pre-yielded bents most likely began cracking at loads less than the other bents due to the fact that they already had pre-existing cracks through their cross-sections, e.g., the "new" cracks in Bent 2N were simply the reopening of the epoxy injected cracks.

The crack propagation direction and growth followed the same pattern as discussed in Rowe (2001). The cracks started at the top of the bent and grew towards the point where the cantilever and column of the bent meet.



## **6. Conclusions and Recommendations**

### **6.1 Concrete Patches**

#### **6.1.1 Conclusions**

With only three test specimens (15N, 15S and 12N) repaired with concrete patches, it is difficult to form any definitive conclusions as to the effectiveness of the patches. This is evidenced by the variations in the results. Bents 15N and 15S increased in stiffness, and decreased in strength, when compared to the pre-yielded bents (2N and 12N) and the bents taken to failure without any repair (1N and 12S). The reverse is true for Bent 12N, which decreased in stiffness and increased in strength when compared to the other bents. It is difficult to ascertain whether these results were a cause of the concrete patches, or whether the bents would have behaved similarly without any repair. Rowe (2001) concluded that as long as the flexural reinforcement in a deteriorated bent is not seriously corroded, the deterioration will not significantly affect the capacity of the bent. In such cases where the flexural reinforcement is not seriously corroded, the concrete patch is not necessary for structural purposes, but meets more of a cosmetic and visual confidence need. The flexural reinforcement in all three concrete repaired bents (15N, 15S and 12N) was not seriously corroded and therefore, the patches most likely did not greatly affect the capacity and stiffness of the bents.

#### **6.1.2 Recommendations**

Any concrete patch must fully encase the exposed reinforcement to be effective. Whether or not a concrete patch serves a structural purpose, the patch can still be necessary before the installation of other repair or strengthening methods, such as CFRP wraps. It is therefore important that the concrete patch is properly installed. In the preparation of bents for concrete patch, it is important to chip away the old concrete around the reinforcement to a depth that fully exposes the bars so that the new concrete can sufficiently surround the entire cross-section of the reinforcement. As a rule of thumb, the depth must be such that the worker must be able to fully grip the rebar. Otherwise, the interface between the old concrete and the new concrete may be weak and the new concrete may fall off, even if the concrete is placed just to meet aesthetics reasons or as a preliminary step for a strengthening procedure.

The type of material is also critical for obtaining a proper concrete patch. Three recommendations are made regarding patch materials: (1) the strength of the patch material must at least match that of the base material, (2) the maximum nominal size of coarse aggregate must not be larger than 1/4 of the distance between exposed reinforcing bars and base material, and (3) the material must contain coarse aggregate. In addition, the patch material must conform to general UDOT guidelines for producing Portland Cement Concrete, except as noted above.

## **6.2 Epoxy Injection**

### **6.2.1 Conclusions**

The results presented in this report indicate that epoxy crack injection does not restore the strength or stiffness of bents. This result is unexpected as previous research—Abu-Tair et al. (1991) and Basunbul et al. (1990)—have found the opposite to be true. One possible reason for this may be that in bent 2N the epoxy did not fully penetrate the entire depth of the cracks. Unlike other specimens, the specimens used in this research had very large cross-sections, thus making the epoxy difficult to flow throughout the entire cross-section. Another possibility is that the epoxy may not have cured properly. The epoxy injection was accomplished during early September. The temperature both at application and during curing may have had an effect on the performance as well as the flow of the epoxy. No matter the reason, it was apparent that bent 2N began cracking at a lower load than the other bents tested, and that those cracks were the reopening of the epoxy injected cracks. This is in direct contrast to the results of Abu-Tair et al. (1991) who found that at prolonged cyclic loads at very high stress levels, the epoxy injected cracks did not reopen. The size of the cross-section may; therefore, be an extremely important consideration during epoxy injection. If the epoxy injection does not restore the strength or stiffness of the bent, however, it will seal the cracks, thus protecting the reinforcement from further corrosion and keep the cracks from opening further due to freeze-thaw cycles.

### **6.2.2 Recommendations**

Repair of cracks by epoxy injection in cross sections larger than 12 inches in any direction shall, in addition of meeting UDOT general epoxy injection and sealing guidelines, be made with a material with cps less than 500 and gel time greater than 5 minutes. In addition, ports shall be placed higher as well as in directly opposing faces to ensure proper flow through the entire cross section.

## **6.3 CFRP Wraps**

### **6.3.1 Conclusions**

Carbon fiber reinforced polymer wraps will not only restore but also increase the strength and stiffness of reinforced concrete bents. The results of this report in regards to CFRP are in agreement with previous findings (Pantelides, et al. 1999). The mode of failure by delamination between the CFRP and the concrete was noted as being similar to that discussed in Norris, et al. (1997) and Chaallal, et al. (1998).

The surface of the bent must be completely free from moisture and the concrete patch must be properly cured. The CFRP wraps began to peel from the concrete. The peeling or debonding may have been a result of moisture in the shotcrete, which may have been too thick to be moisture free within the seven days of curing before the CFRP wraps were applied to the bent.

Proper anchorage of CFRP wraps to concrete bents is an important consideration. Bonding of the development length to the concrete may not be sufficient to ensure reasonable performance due to imperfections on the surface of the bent, which may cause peeling of the wraps. On Bent 13S the CFRP wrap “development length” was properly bonded but not properly anchored, which resulted in premature failure of the system. The anchoring fiber bolts used in this research may be an effective way to prevent peeling of the ends of the wrap. The anchoring fiber bolts, however, must be properly installed to function as anchoring devices for the ends of the wrap.

### **6.3.2 Recommendations**

The surface as well as the concrete patch must be completely free from moisture. The results of this research indicate that seven days may not be enough to attain a

moisture free concrete patch. The scope of this research program did not include determination of a relationship between thickness of concrete patches and time to attain a moisture free concrete patch. Thus a recommendation as to how long a concrete patch must be cured to be completely moisture free is not given. The authors, however, caution the end users of this report to the fact that seven days may not be sufficient to attainment of a moisture free concrete patch.

Best performance will be obtained if bents are wrapped around and continuously along its length similar to the wrapping of a column. In case such a procedure is not possible, it is recommended that the ends of the wraps be anchored. Such anchoring may be achieved by either a fiber bolt systems or a steel plate —steel bolts system. In either case, the system must be properly installed.

In addition to these two recommendations, the UDOT special provisions for bent composite wrap shall be followed.

## 7. References

Abu-Tair, A.I. (University of London); Rigden, S.R.; and Burley, E., "Effectiveness of the Resin Injection Repair Method for Cracked RC Beams," *Structural Engineer*, Vol. 69, No. 19, Oct. 1991, pp. 335-341

Arduini, M.; and Nanni, A., "Behavior of Precracked RC Beams Strengthened with Carbon FRP Sheets," *Journal of Composites for Construction*, Vol. 1, No. 2, May 1997, pp. 63-70

Basnubul, I.A.; Gubati, A.A.; Al-Sulaimani, G.J.; and Baluch, M.H.; "Repaired Reinforced Concrete Beams," *ACI Materials Journal*, Vol. 87, No. 4, Jul.-Aug. 1990, pp. 348-354

Chaallal, O.; Nollet, M.-J.; and Perraton, D., "Strengthening of Reinforced Concrete Beams with Externally Bonded Fiber Reinforced Plastic Plates: Design Guidelines for Shear and Flexure," *Canadian Journal of Civil Engineering*, Vol. 25, 1998, pp. 692-704

Khan, Akhtar S., and Wang, Xinwei, *Strain Measurements and Stress Analysis*, Prentice Hall, New Jersey, 2001

Mays, G.C. (Cranfield University); and Barnes, R.A., "Structural Effectiveness of Large Volume Patch Repairs to Concrete Structures," *Proceedings of the Institution of Civil Engineers, Structures and Buildings*, Vol. 110, No. 4, Nov. 1995, pp. 351-360

Meier, U.; and Kaiser, H., "Strengthening of Structures with CFRP Laminates," *Proc., Advanced Composites Materials in Civil Engineering Structures*, American Society of Civil Engineers, pp. 224-232

Pantelides, C.P.; Gergely, J.; Reaveley, L.D.; and Volnyy, V.A., "Retrofit of RC Bridge Pier with CFRP Advanced Composites," *Journal of Structural Engineering*, Vol. 125, No. 10, October 1999, pp. 1094-1099

Norris, T.; Saadatmanesh, H.; and Ehsani, M.R., “Shear and Flexural Strengthening of RC Beams with Carbon Fiber Sheets,” *Journal of Structural Engineering*, Vol. 123, No. 7, July 1997 pp. 903-911

Raoof, M. (Loughborough University); and Lin, Z., “Structural Characteristics of RC Beams with Exposed Main Steel,” *Proceedings of the Institution of Civil Engineers, Structures and Buildings*, Vol. 122, No. 1, February 1997, pp. 35-51

Rowe, Mark David, “Flexural Performance of Deteriorated Reinforced Concrete Bridge Bents,” Master’s Thesis, Brigham Young University, August 2001

Utah Department of Transportation, “Standard Specifications for Road and Bridge Construction,” Salt Lake City, Utah, 2002

Utah Department of Transportation, “Special Provisions—Bent Composite Wrap,” Salt Lake City, Utah, 1999

## TABLES

Table 1.1 – Predicted Bent Capacities

		Shear (kips)	corresponding to a load of: (kips)	Flexure (kip-ft)	corresponding to a load of: (kips)
WSD		226	226	1426	228
USD		476	476	3028	484
Moment Curvature	Response	---	---	3144	740
	BIAX	---	---	2757	649
	Hand Calcs.	---	---	2514	592

Table 3.1 – Displacement LVDT's and String pots

Name	Range	Measuring displacement of:
LV1	±6 in.	cantilever arm
LV2	±6 in.	cantilever arm
LV3	±6 in.	cantilever arm
LV4	±6 in.	cantilever arm
LV5	±6 in.	cantilever arm
LV6	±6 in.	cantilever arm
LV7	±6 in.	clamped end of bent
LV8	±2 in.	column of bent
LV9	±6 in.	shear beam with actuators
LV10	±2 in.	shear beam with strong beam
SP1	±10 in.	strong beam
SP2	±10 in.	cantilever arm
SP3	±10 in.	cantilever arm
SP4	±10 in.	cantilever arm
SP5	±10 in.	cantilever arm
SP6	±10 in.	cantilever arm
SP7	±10 in.	cantilever arm



Table 4.1 – Peak loads and deflections for each push on bent 15N

Bent 15N	First Push		Second Push		Third Push	
	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)
Cycle 1	158	0.26	163	0.25	162	0.23
Cycle 2	244	0.27	248	0.25	245	0.23
Cycle 3	364	0.32	360	0.32	365	0.32
Cycle 4	402	0.35	405	0.36	402	0.35
Cycle 5	607	0.62	563	0.64	564	0.64
Cycle 6	637	1.38	589	1.90	591	1.98
Cycle 7	625	2.91	594	2.92	591	2.91
Cycle 8	630	3.55				

Table 4.2 – Peak loads and deflections for each push on bent 15S

Bent 15S	First Push		Second Push		Third Push	
	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)
Cycle 1	83	0.04	86	0.04	93	0.04
Cycle 2	169	0.10	164	0.10	166	0.09
Cycle 3	242	0.16	250	0.17	247	0.16
Cycle 4	363	0.28	363	0.30	363	0.30
Cycle 5	403	0.37	404	0.38	401	0.38
Cycle 6	598	0.63	572	0.63	576	0.62
Cycle 7	635	1.70	572	1.74	577	1.74
Cycle 8	597	1.95	599	2.95		

Table 4.3 – Peak loads and deflections for each push on bent 2N

Bent 2N	First Push		Second Push		Third Push	
	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)
Cycle 2	171	0.13	165	0.13	165	0.13
Cycle 3	242	0.23	241	0.24	244	0.25
Cycle 4	362	0.42	366	0.43	365	0.44
Cycle 5	405	0.49	407	0.49	402	0.49
Cycle 6	588	0.76	552	0.77	553	0.77
Cycle 7	632	1.97	587	1.97	589	2.00
Cycle 8	657	2.78	625	2.79	614	2.79
Cycle 9	671	3.26	640	3.76	622	3.75
Cycle 10	663	4.27				

Table 4.4 – Peak loads and deflections for each push on bent 12N

Bent 12N	First Push		Second Push		Third Push	
	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)
Cycle 1	86	0.13	91	0.14	91	0.14
Cycle 2	157	0.22	164	0.22	161	0.21
Cycle 3	247	0.35	247	0.36	247	0.36
Cycle 4	324	0.50	333	0.52	327	0.53
Cycle 5	397	0.76	401	0.73	410	0.75
Cycle 6	522	0.96	489	0.93	482	0.91
Cycle 7	653	1.62	596	1.59	596	1.52
Cycle 8	676	2.42	617	2.62	610	2.64
Cycle 9	678	3.58	649	3.70	632	3.70
Cycle 10	761	7.05				

Table 4.5 – Peak loads and deflections for each push on bent 13S

Bent 13S	First Push		Second Push		Third Push	
	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)
Cycle 1	87	0.02	112	0.02	106	0.02
Cycle 2	157	0.04	161	0.04	166	0.04
Cycle 3	302	0.14	306	0.12	299	0.11
Cycle 4	400	0.15	400	0.13	406	0.12
Cycle 5	505	0.20	495	0.22	499	0.24
Cycle 6	661	0.40	703	0.48	650	0.49
Cycle 7	762	0.65	724	0.65	719	0.65
Cycle 8	744	0.85				

Table 4.6 – Peak loads and deflections for each push on bent 13N

Bent 13N	First Push		Second Push		Third Push	
	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)	Load (kips)	Defl. (in)
Cycle 4	392	0.15	403	0.16	408	0.17
Cycle 5	501	0.22	501	0.23	505	0.25
Cycle 6	608	0.30	587	0.30	565	0.29
Cycle 7	761	0.41	704	0.40	678	0.39
Cycle 8	849	0.58	789	0.57	761	0.56
Cycle 9	873	0.75	758	0.73	737	0.72
Cycle 10	882	0.92				

Table 5.1 – Test Results for all bents

Bent	Retrofitting Scheme	Yield Load kip	Yield Defl. in	Ult. Load kip	Ult. Load Defl. In	Stiffness kip/in
1N		588	0.90	708	3.28	850
12S		625	0.78	709	5.56	800
2N	Epoxy	585	0.83	671	3.31	650
2N		562*	0.48	-	-	880
12N	Patch	628	1.21	761	7.05	600
12N		559*	0.61	-	-	840
15N	Patch	605	0.58	637	1.80	1350
15S	Patch	601	0.64	635	1.70	1040
13S	CFRP Wrap	500	0.65	762	0.65	2100
13N	CFRP Wrap	761	0.41	882	0.92	2200

\* Estimated

- The shaded bents were tested in Rowe (2001) and the results are included in this table for comparison purposes.

## FIGURES



Figure 1.1 – Destruction of superstructure over Bents 12, 13, and 14 (Rowe, 2001)



Figure 1.2 – Securing a bent without harming the cantilever (Rowe, 2001)



Figure 2.1 – West side and underneath cantilever of Bent 15N



Figure 2.2 – East side of Bent 15N in pre-repair condition





Figure 2.2a – Close-up of longitudinal reinforcement on Bent 15N

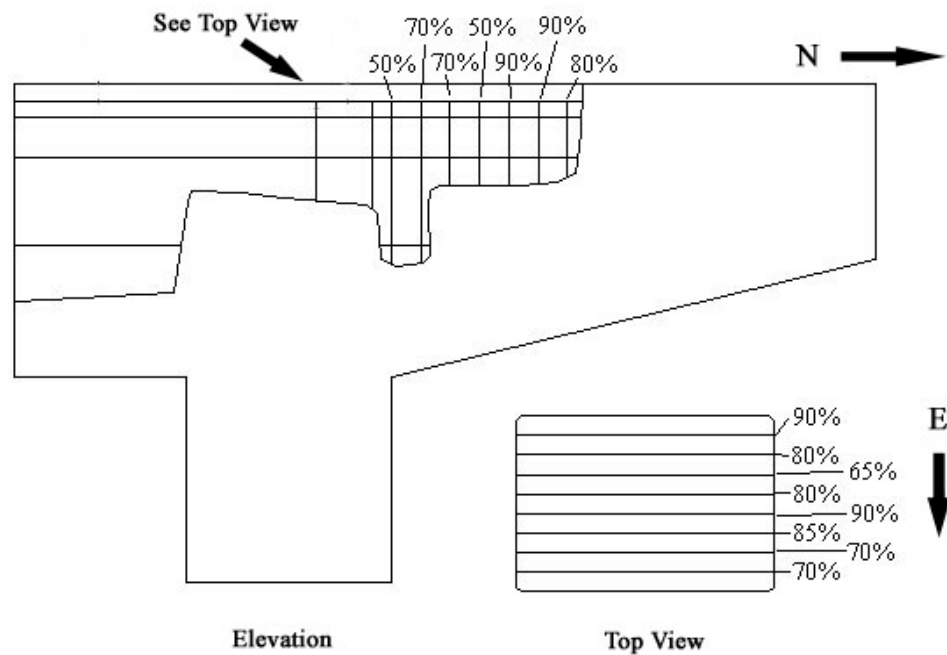


Figure 2.3 – Schematic drawing of exposed rebar on Bent 15N (percentage represents rebar remaining)



Figure 2.4 – Bent 15N with bottom portions patched



Figure 2.5 – Completely repaired East side of Bent 15N





Figure 2.6a – Bent 15S in place



Figure 2.6b – Bent 15S, close-up of East face



Figure 2.6c – Bent 15S, close-up of east face and underside of cantilever



Figure 2.6d – Bent 15S, close-up of cantilever face and underside





Figure 2.6e – Bent 15S, west face and underside of cantilever



(a) East face



(b) Underside of cantilever

Figure 2.7 – Bent 15S after loose concrete chipped away



(a) Cantilever tip



(b) Close-up of shear reinforcement

Figure 2.8 – Rebar fully exposed on Bent 15S

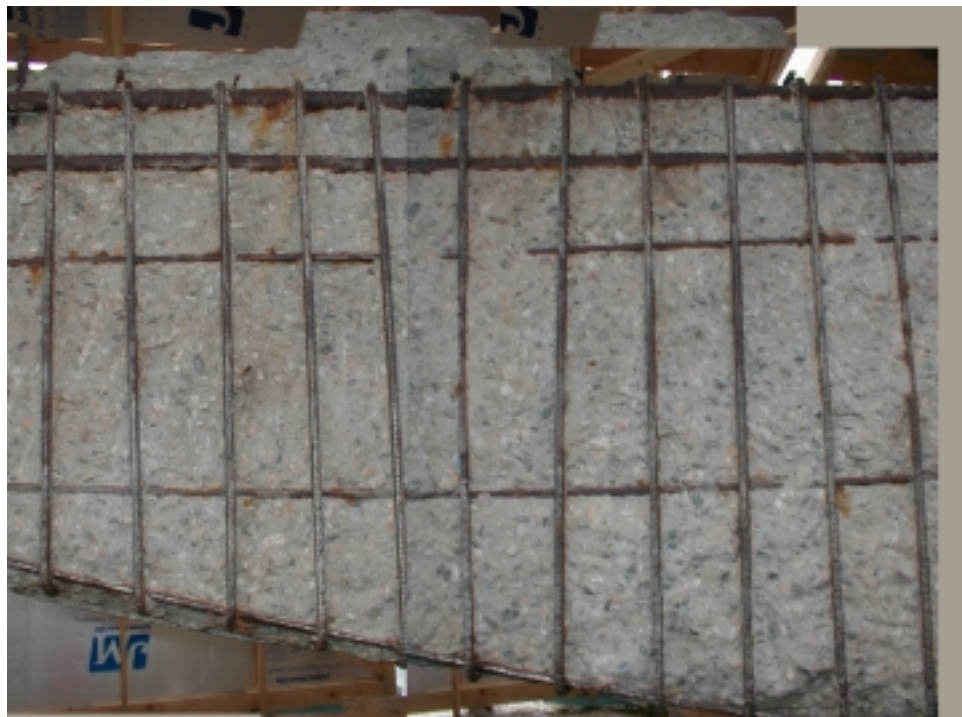


Figure 2.9 – Condition of Bent 15S before concrete patch





Figure 2.10 – Rebar on Bent 15S after removal of rust



Figure 2.11 – Bent 15S coated with bonding agent

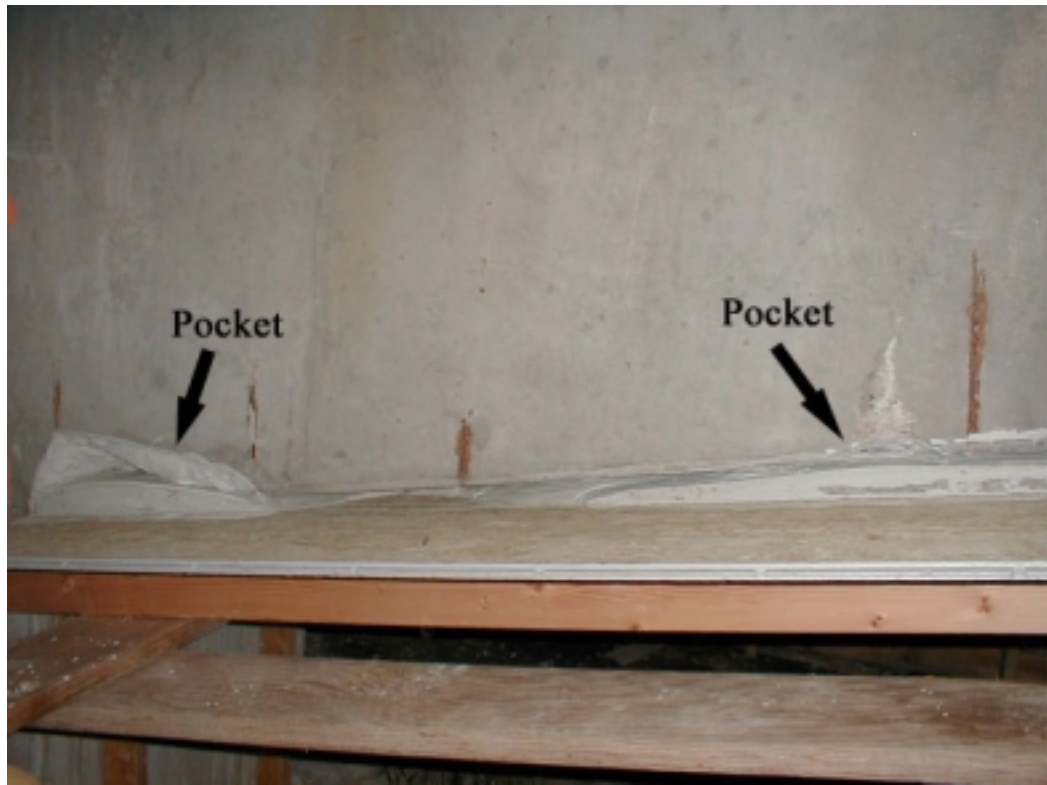


Figure 2.12 – Pockets in concrete on Bent 15S



Figure 2.13 – New forms on Bent 15S to fix void gaps



Figure 2.14 – Edge of Bent 15S





Figure 2.15 – Concrete forms on Bent 15S



Figure 2.16 – East side of repaired Bent 15S





Figure 2.17 – Cantilever of repaired Bent 15S



Figure 2.18 – Underside of cantilever of repaired Bent 15S



Figure 2.19 – Bent 15S before repair (cracks drawn on picture)



Figure 2.20 – East side of Bent 2N



Figure 2.21 – West side of Bent 2N



Figure 2.22 – Cracks in Bent 2N after pre-yield test





Figure 2.23 – Epoxy injection tubes and surface seal on Bent 2N



Figure 2.24 – Location of epoxy injected cracks on east side of Bent 2N



Figure 2.25 – Location of epoxy injected cracks on West side of Bent 2N



Figure 2.26 – Condition of the East side of Bent 12N before repair





Figure 2.27 – Underside of the cantilever of Bent 12N before repair



Figure 2.28 – Intersection of the cantilever and column of Bent 12N before repair



Figure 2.29 – East side of Bent 13S before repair



Figure 2.29a – Bent 13S in place





Figure 2.29b – Bent 13S, East face and underside of cantilever



Figure 2.29c – Bent 13S, face and underside of cantilever





Figure 2.29d – West face of Bent 13S



Figure 2.30 – West side of Bent 13S before repair



Figure 2.31 – Underside of the non-cantilever of Bent 13S before repair

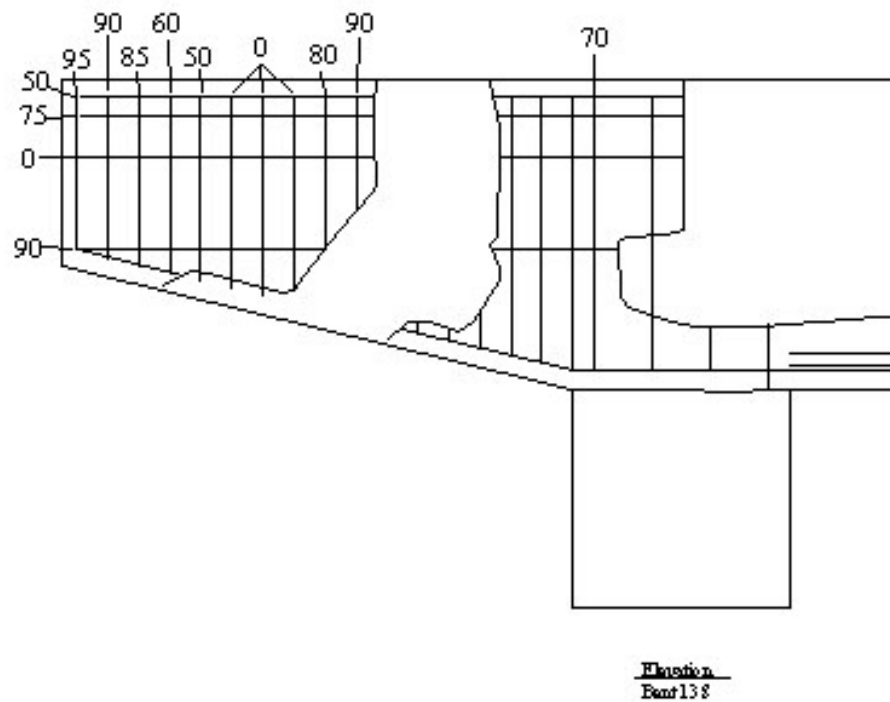


Figure 2.32 – Rebar corrosion on East face of Bent 13S (percentage of rebar remaining)



Figure 2.33 – Concrete chipped away around rebar on Bent 13S



Figure 2.34 – Condition of Bent 13S after concrete was chipped away





Figure 2.35 – East side of Bent 13S after concrete was chipped away



Figure 2.36 – Bent 13S after concrete was chipped away



Figure 2.37 – Hydro jetting of Bent 13S



Figure 2.38 – Concrete surface; upper portion: hydro-jetted, bottom portion: normal





Figure 2.39 – Application of shotcrete to east face of Bent 13S



Figure 2.40 – Application of shotcrete to west face of Bent 13S



Figure 2.41 – Bent 13S partially patched with shotcrete

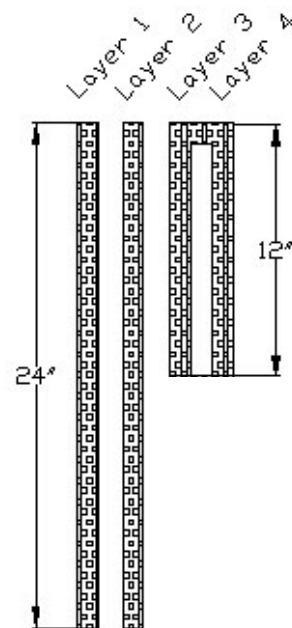


Figure 2.42 – CFRP wrap layout



Figure 2.43 – FRP layers being coated with epoxy before application to bent



Figure 2.44 – FRP being applied to Bent 13S



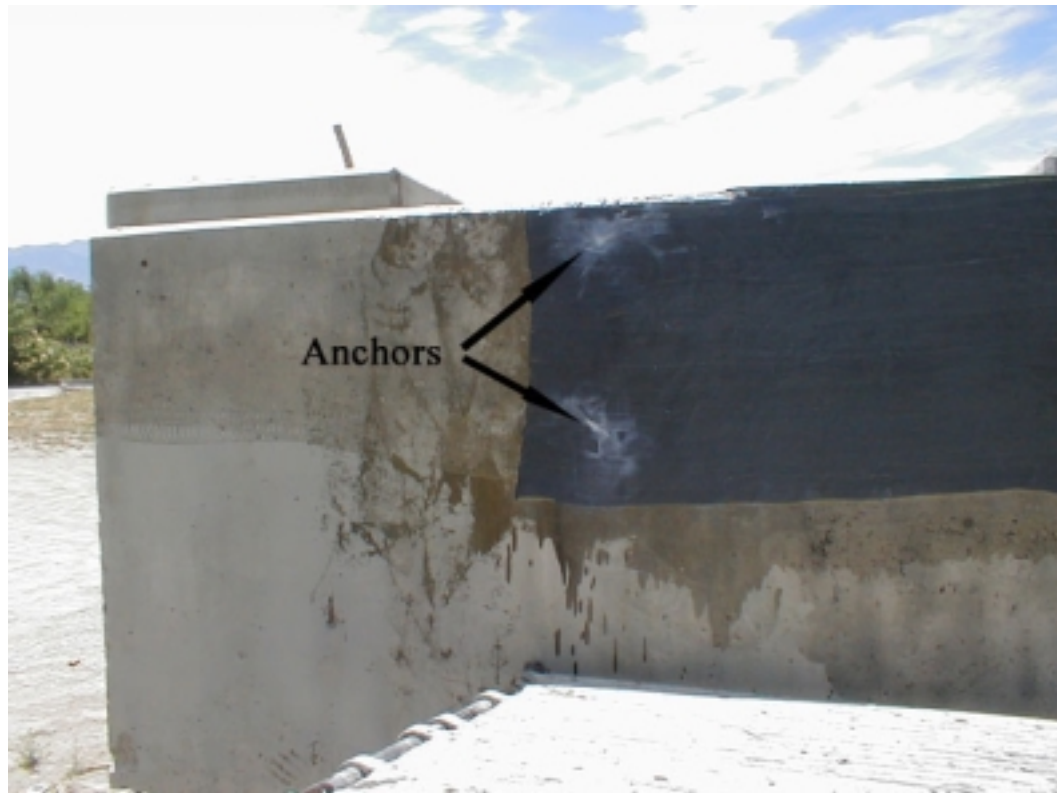


Figure 2.45 – Anchors in FRP and bent



Figure 2.46 – Front view of Bent 13S after application of FRP wraps



Figure 2.47 – East face of Bent 13S after application of FRP wraps



Figure 2.48 – East face of Bent 13N before repair





Figure 2.49 – Bottom of the end portion of Bent 13N



Figure 2.50 – West face of 13N



Figure 2.51 – Bottom of the cantilever of 13N



Figure 2.52 – Overall West face of Bent 13N





Figure 2.53 – West face of Bent 13N after complete removal of unsound concrete



Figure 2.54 – Bottom end portion of Bent 13N after removal of unsound concrete



Figure 2.55 – Overall end portion of Bent 13N after removal of unsound concrete



Figure 2.56 – Bent 13N coated with epoxy where FRP wraps will be placed





Figure 2.57 – Bent 13N after FRP wraps were placed



Figure 2.58 – Anchorage bolt



Figure 2.59 – Array of anchorage bolts



Figure 2.60 – Steel plates





Figure 2.61 – Installing steel plates on bent



Figure 2.62– Anchorage plates and bolts

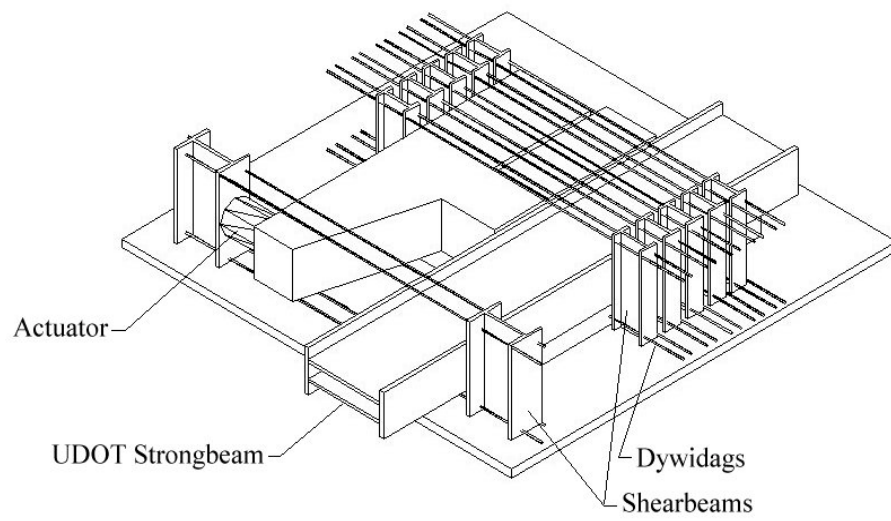


Figure 3.1 – Test Frame (Rowe, 2001)



Figure 3.2 – Concrete pad (Rowe, 2001)



Figure 3.3 – Completed test frame with bent in place



Figure 3.4 – Load frame used for the first two tests





Figure 3.5 – New load frame before concrete was poured



Figure 3.6 – New load frame

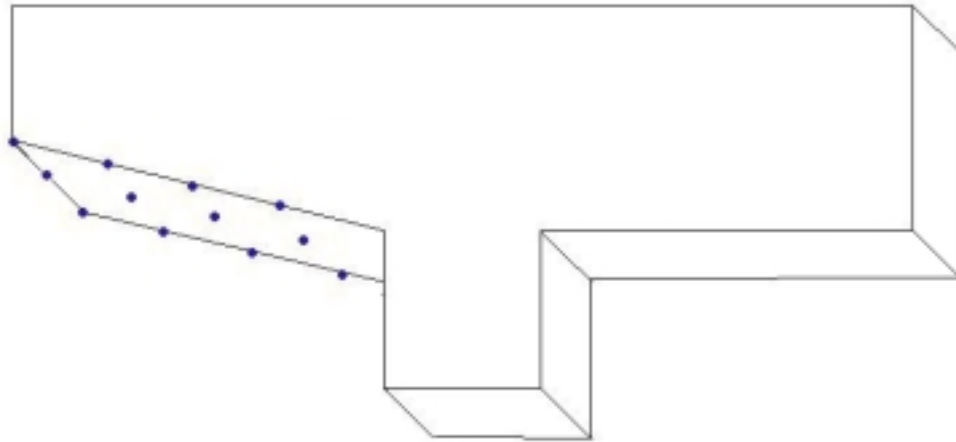


Figure 3.7 – Location of Deflection Measurements (Rowe, 2001)

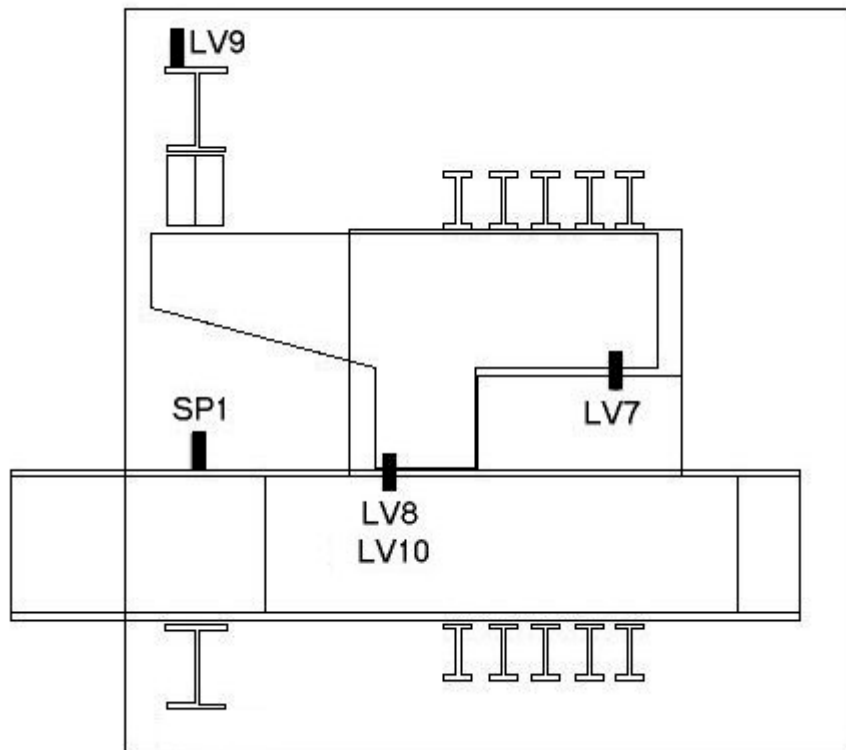


Figure 3.8 – Location of LVDT's on testing frame (Rowe, 2001)



Figure 3.9 – Positioning of load cells

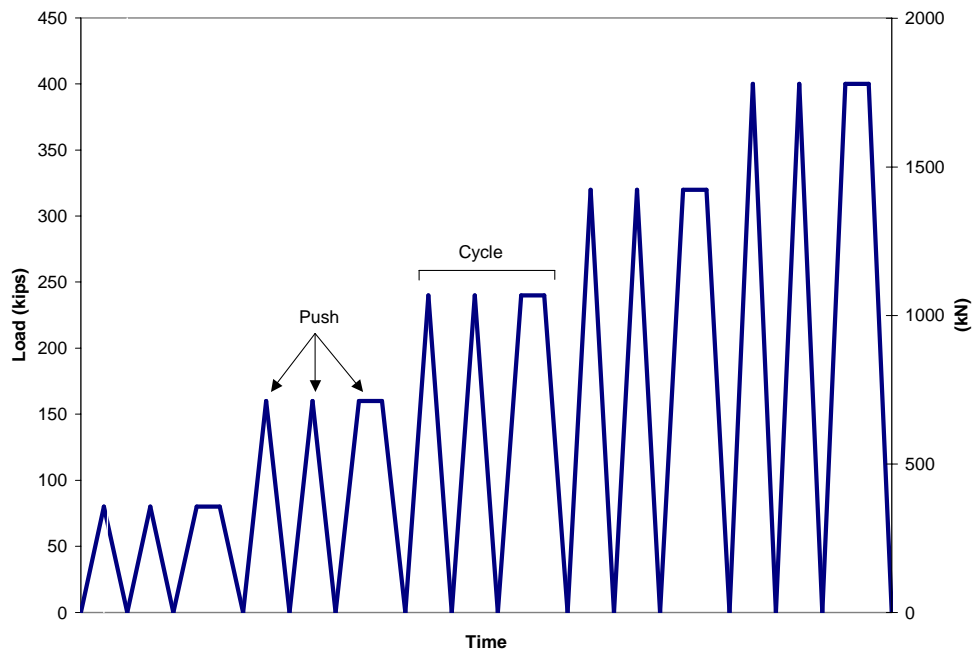


Figure 3.10 – Loading Protocol for load controlled portion of tests (Rowe, 2001)

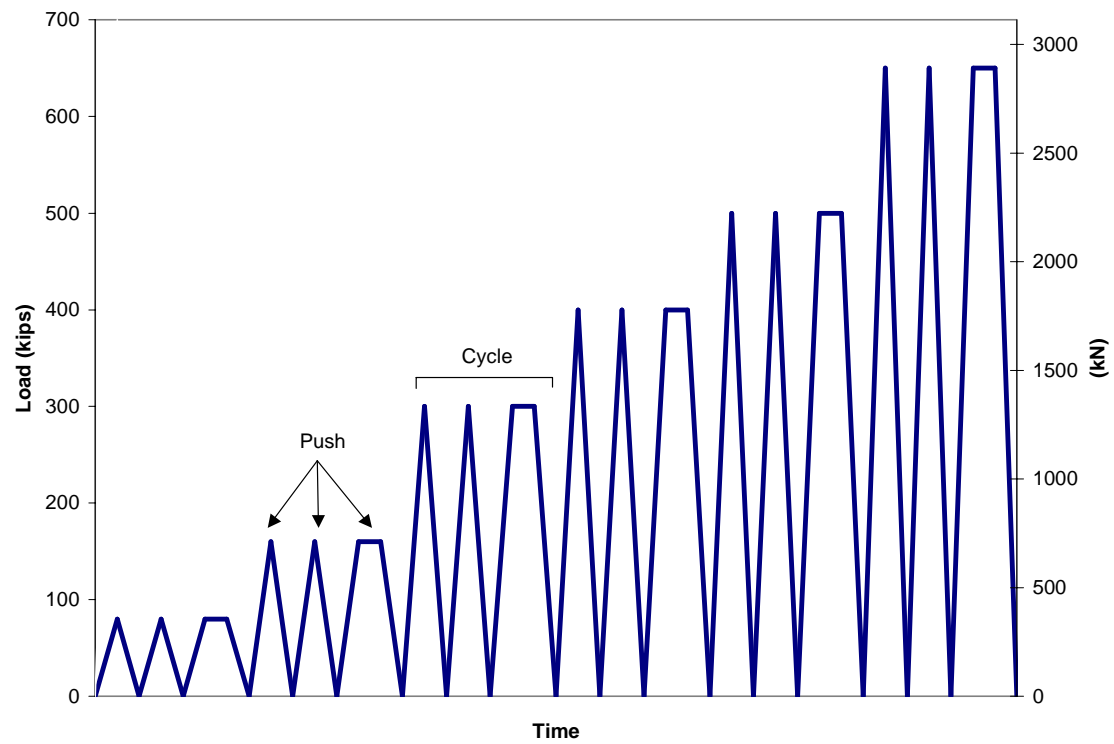


Figure 3.11 – Loading Protocol for load controlled portion of test 13S (Rowe, 2001)



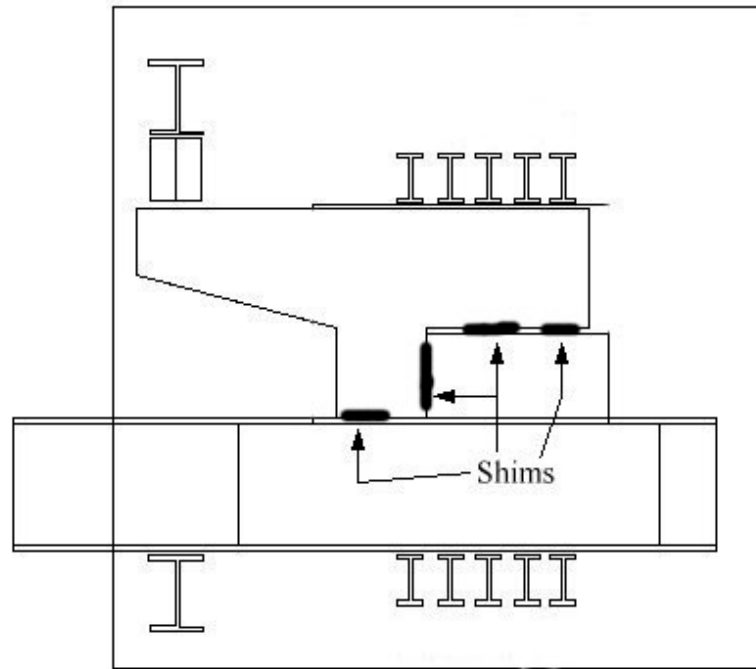


Figure 4.1 – Location of steel shims to help limit free-body motion



Figure 4.2 – Cracks caused by stress concentrations at shim location

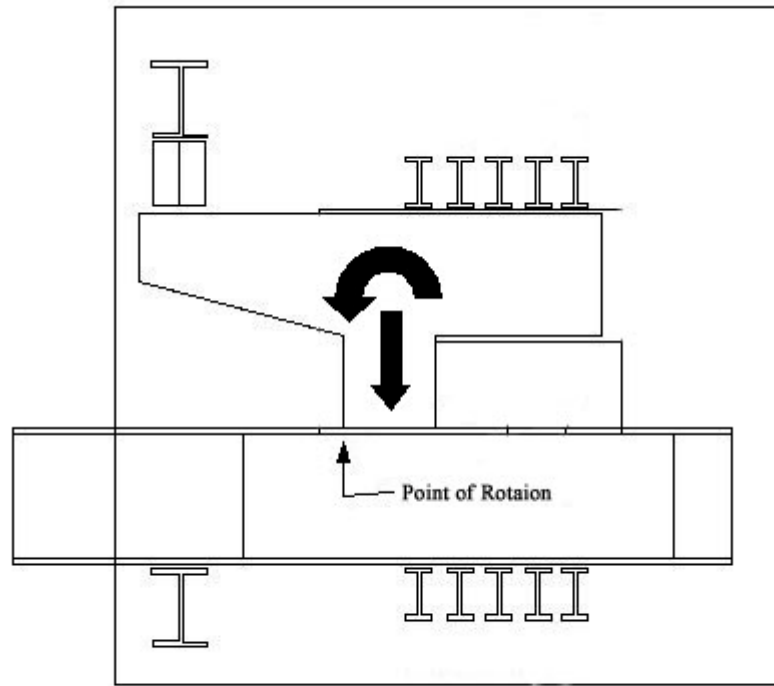


Figure 4.3 – Direction of rotation and translation in free-body motion

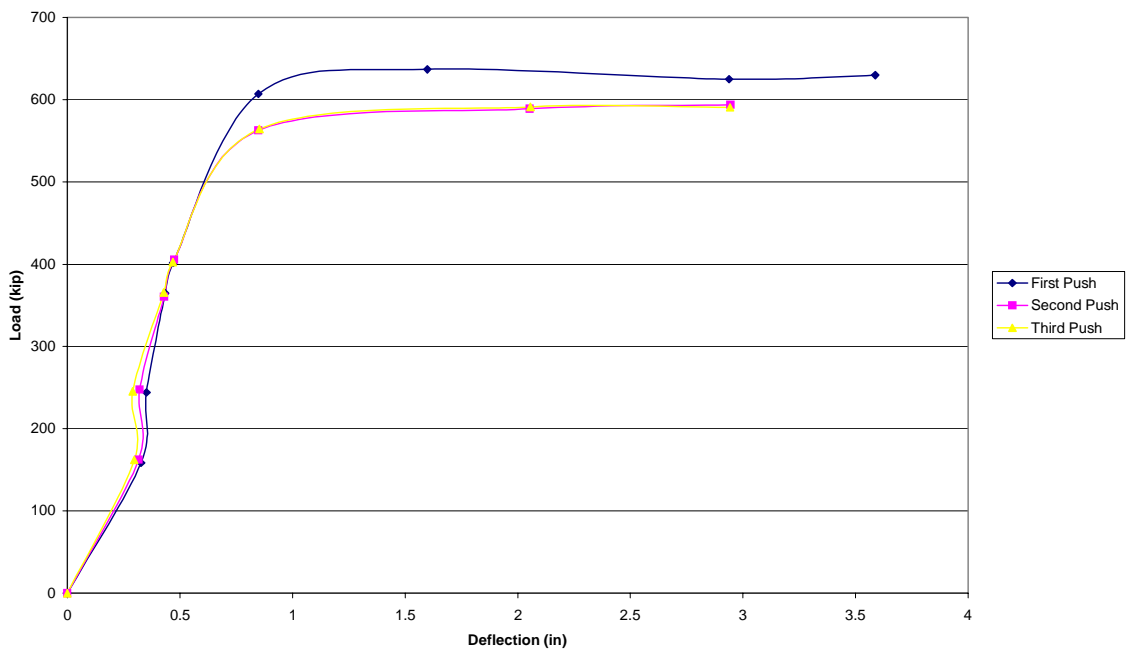


Figure 4.4 – Peak Loads of each push for Bent 15N

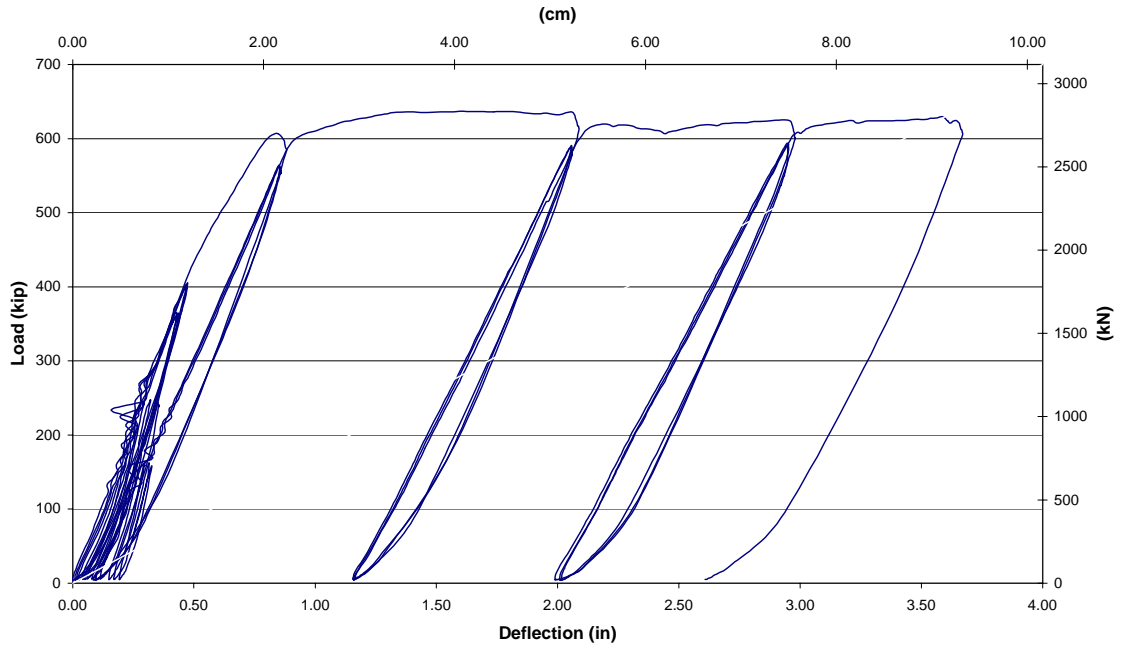


Figure 4.5 – Original Load vs. Deflection for Bent 15N

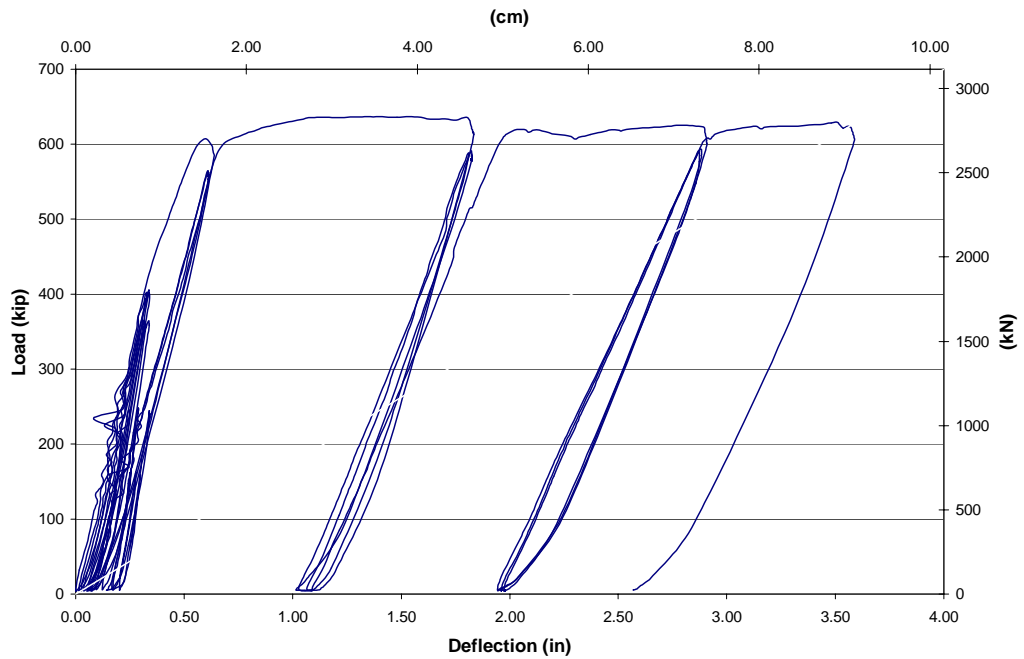


Figure 4.6 – Corrected Load vs. Deflection for Bent 15N

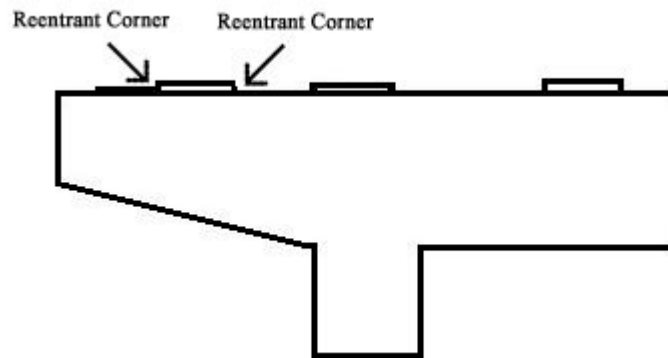


Figure 4.7 – Reentrant corners in girder pedestals and shear key (Rowe, 2001)

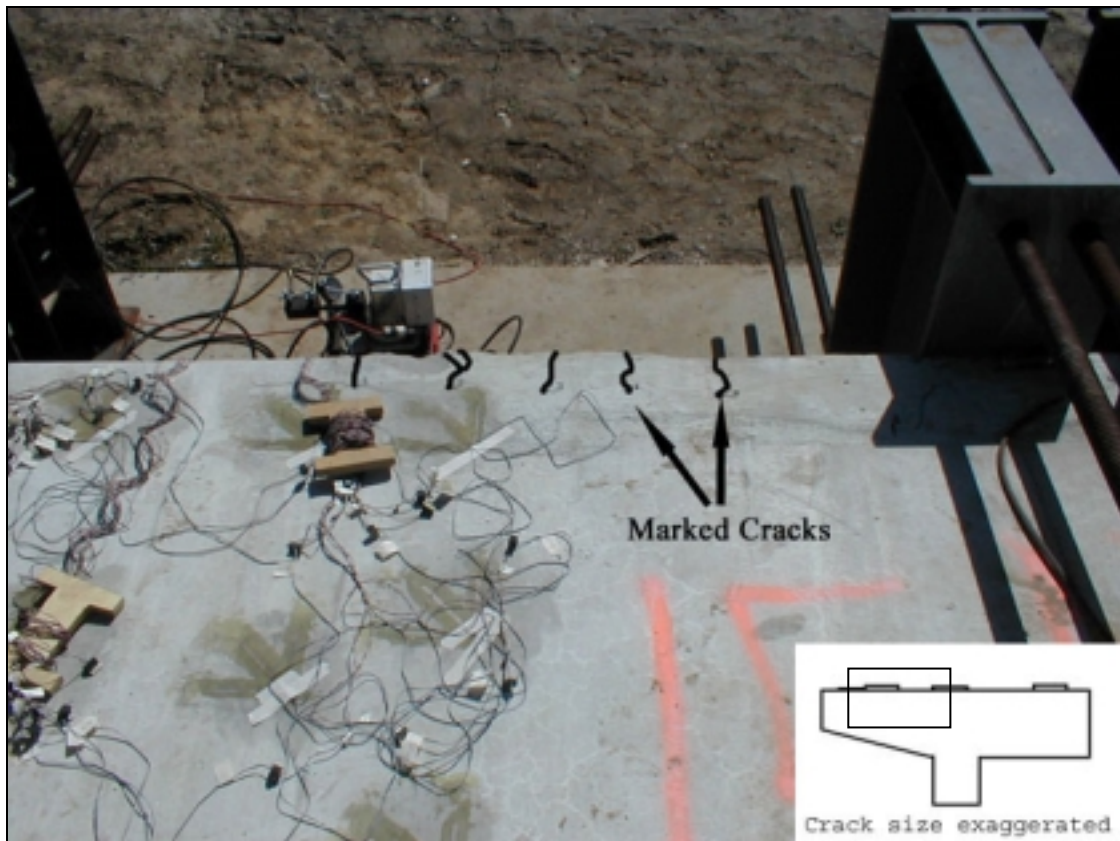


Figure 4.8 – Bent 15N, cracks on cycle 3



Figure 4.9 – Bent 15N, cracks on cycle 4

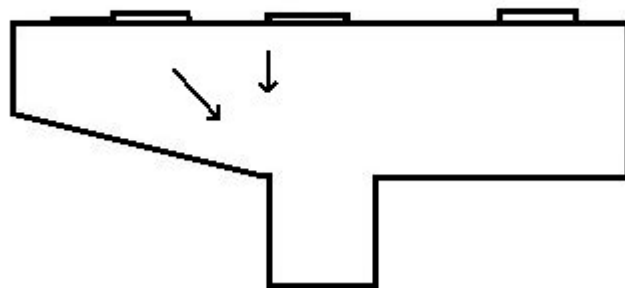


Figure 4.10 – Direction of crack propagation (Rowe, 2001)



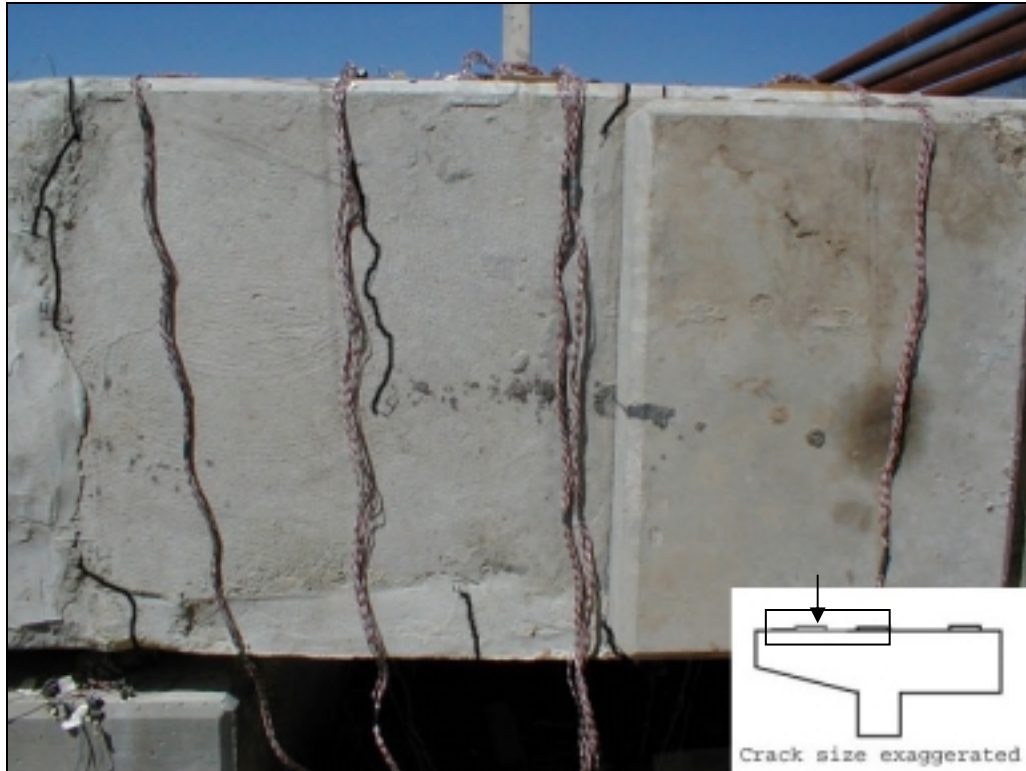


Figure 4.11 – Opening of shrinkage cracks on top of Bent 15N

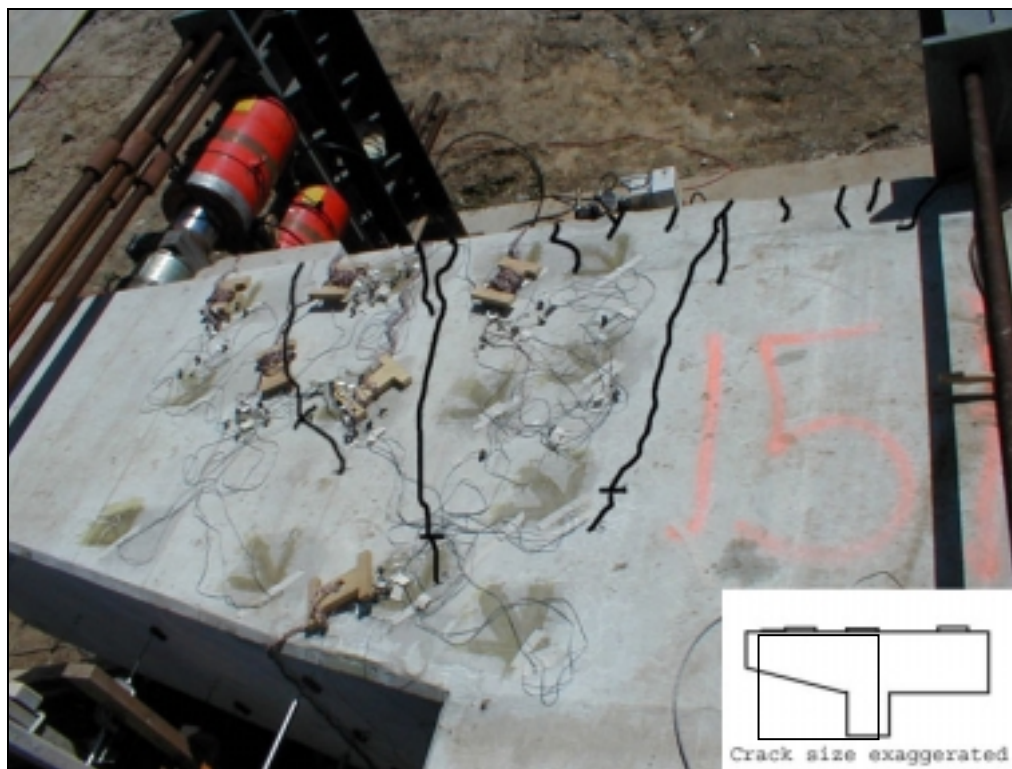


Figure 4.12 – Further propagation of cracks, cycle 5



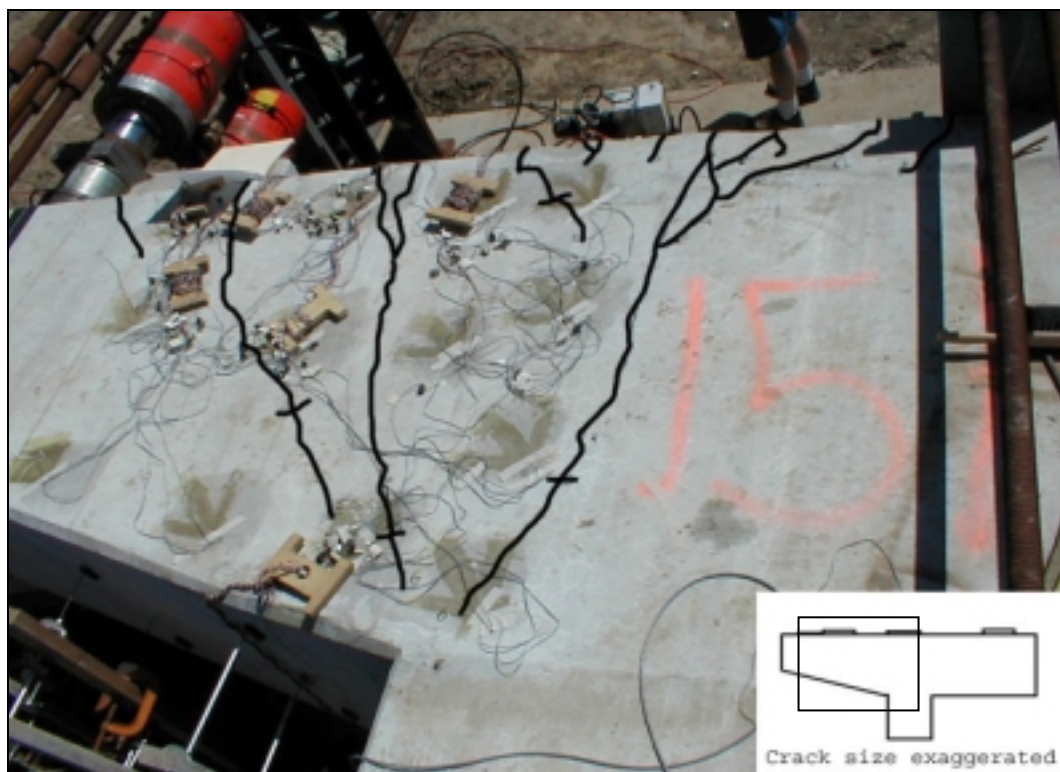


Figure 4.13 – Further propagation of cracks, cycle 6



Figure 4.14 – New cracks formed on Bent 15N, cycle 7



Figure 4.15 – Crushing and spalling of concrete in compression zone of Bent 15N



Figure 4.16 – Cracks at failure, cycle 8, Bent 15N

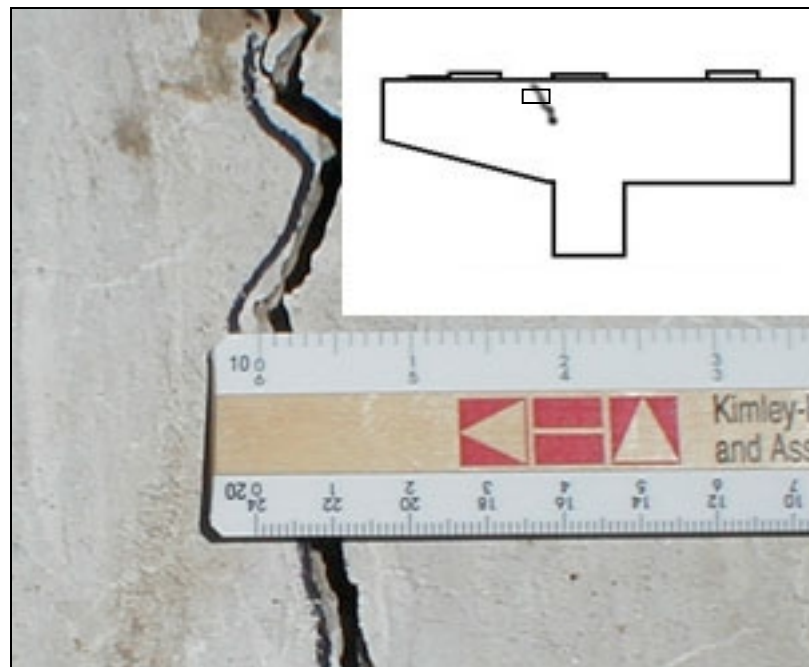


Figure 4.17 – Cracks of approximately 0.20 in (5 mm), cycle 7, Bent 15N



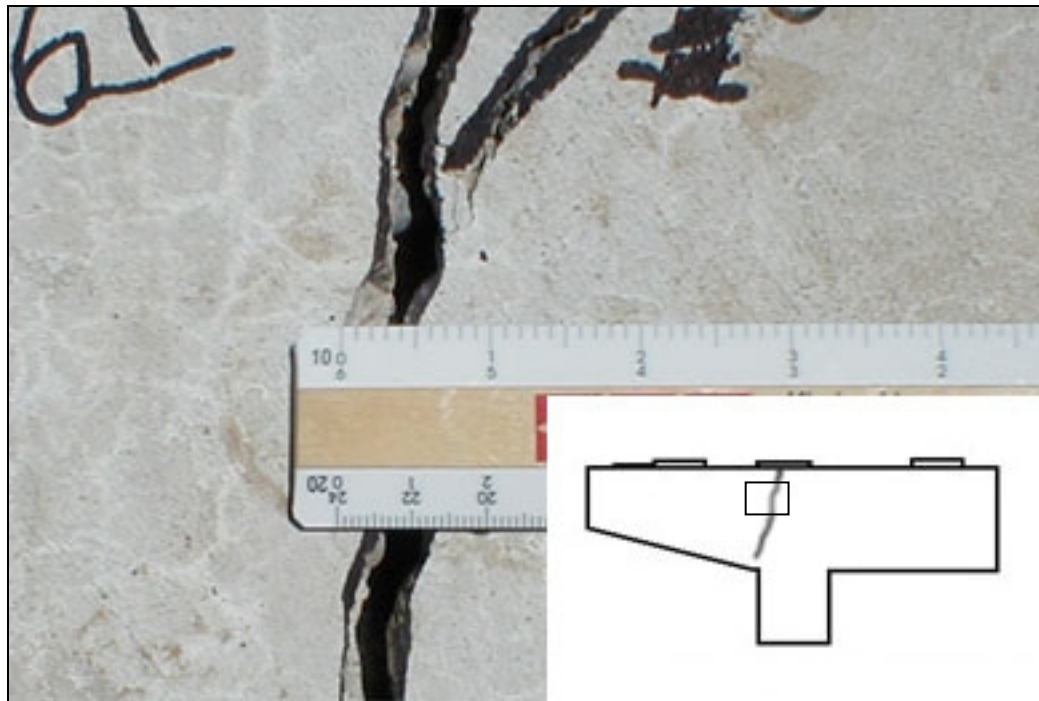


Figure 4.18 – Cracks of approximately 0.5 in (13 mm), cycle 7, Bent 15N

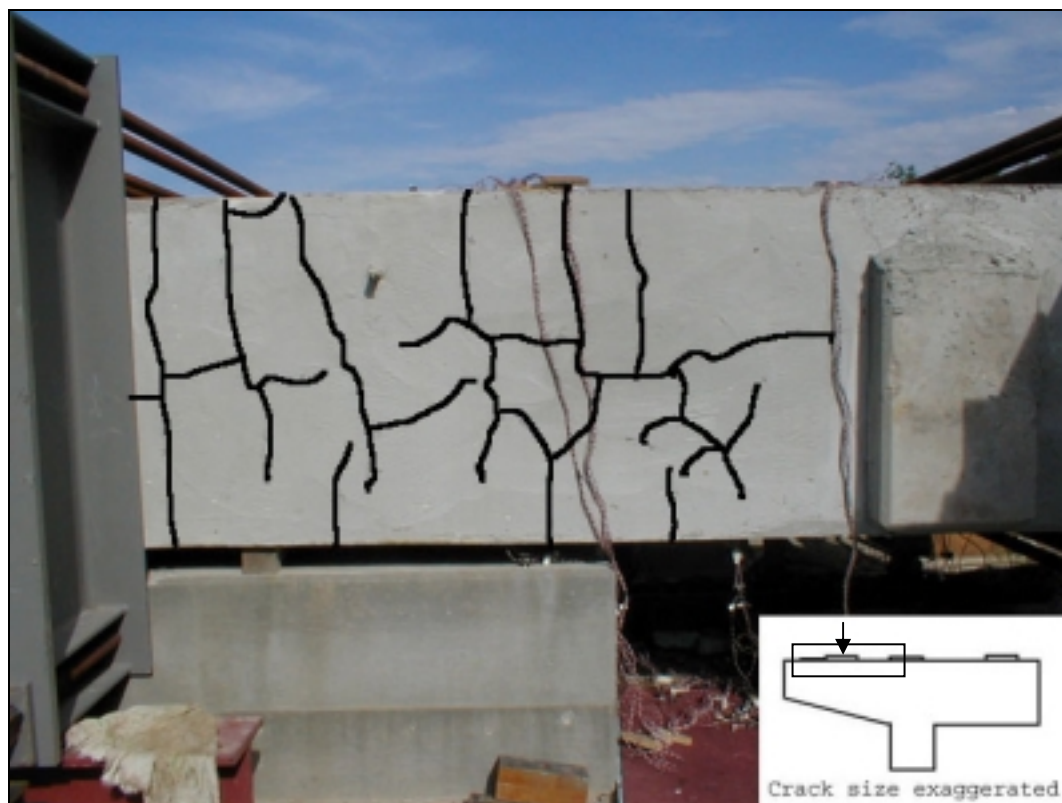


Figure 4.19 – Bent 15S, shrinkage cracks on top of Bent

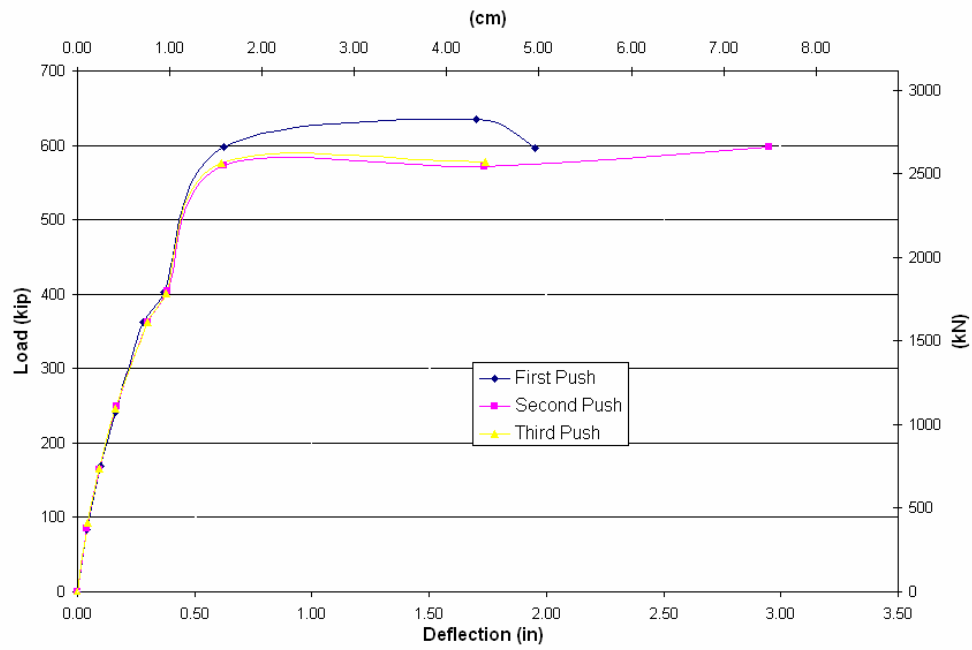


Figure 4.20 – Peak Loads of each push for Bent 15S

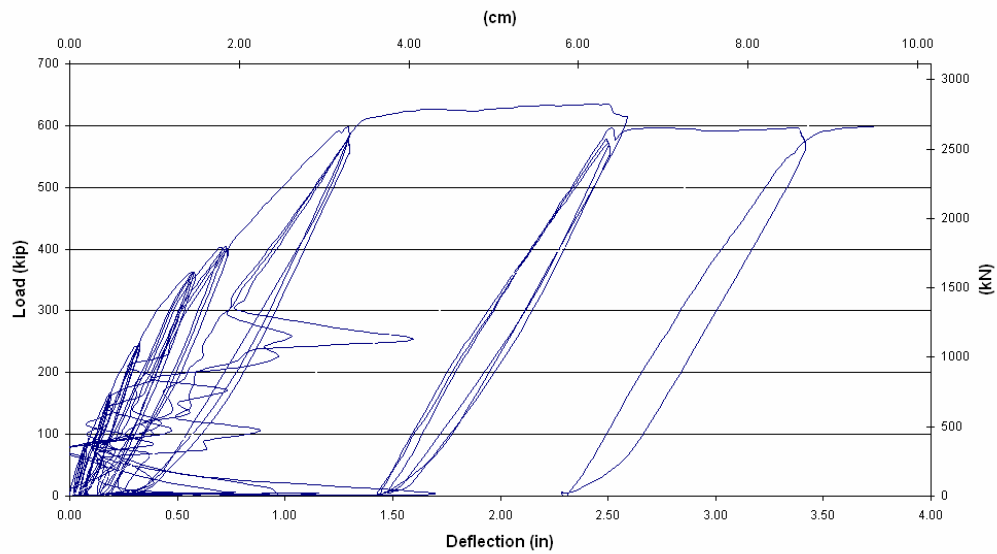


Figure 4.21– Original Load vs. Deflection for Bent 15S

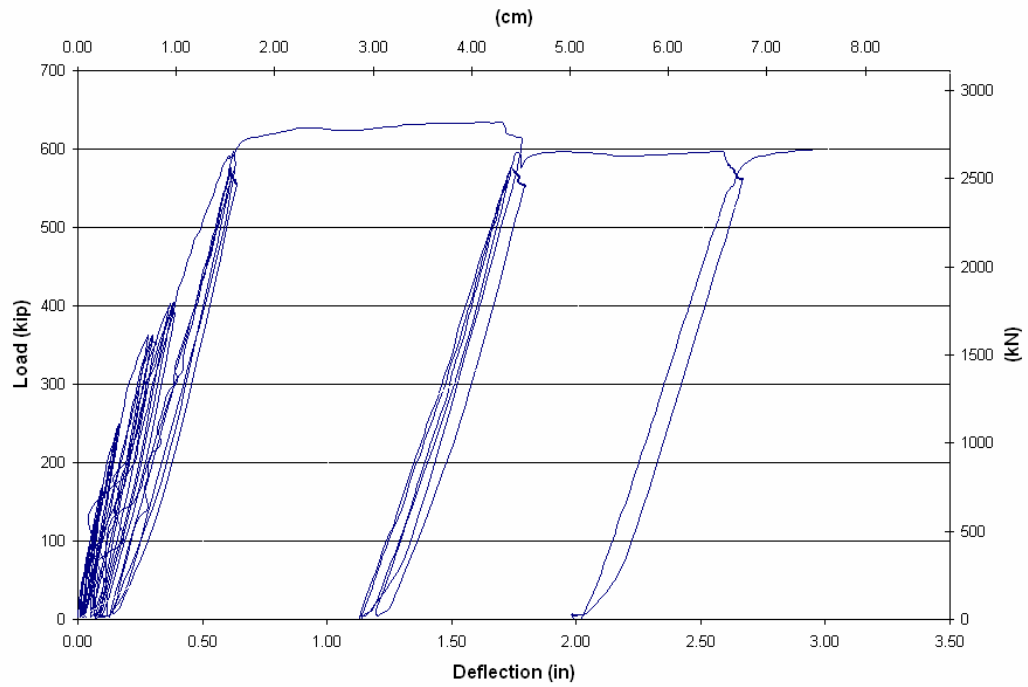


Figure 4.22– Corrected Load vs. Deflection for Bent 15S

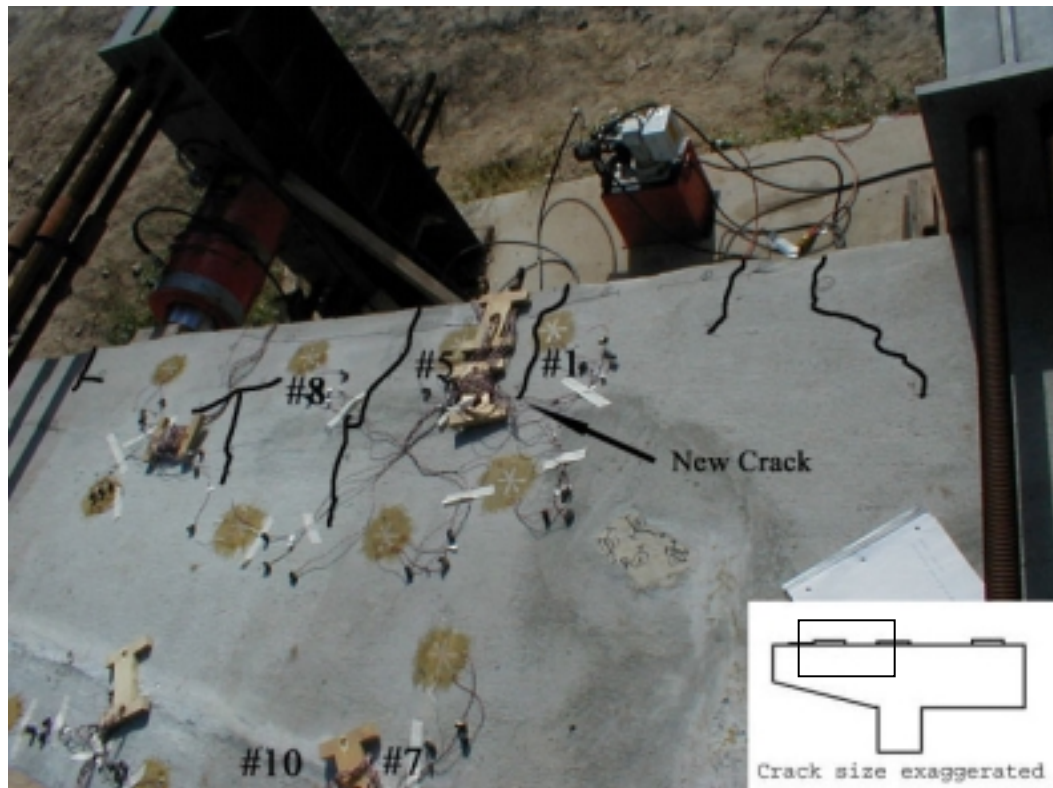


Figure 4.23 – Bent 15S, initiation of cracks, cycle 4





Figure 4.24 – Propagation of cracks, cycle 5, Bent 15S

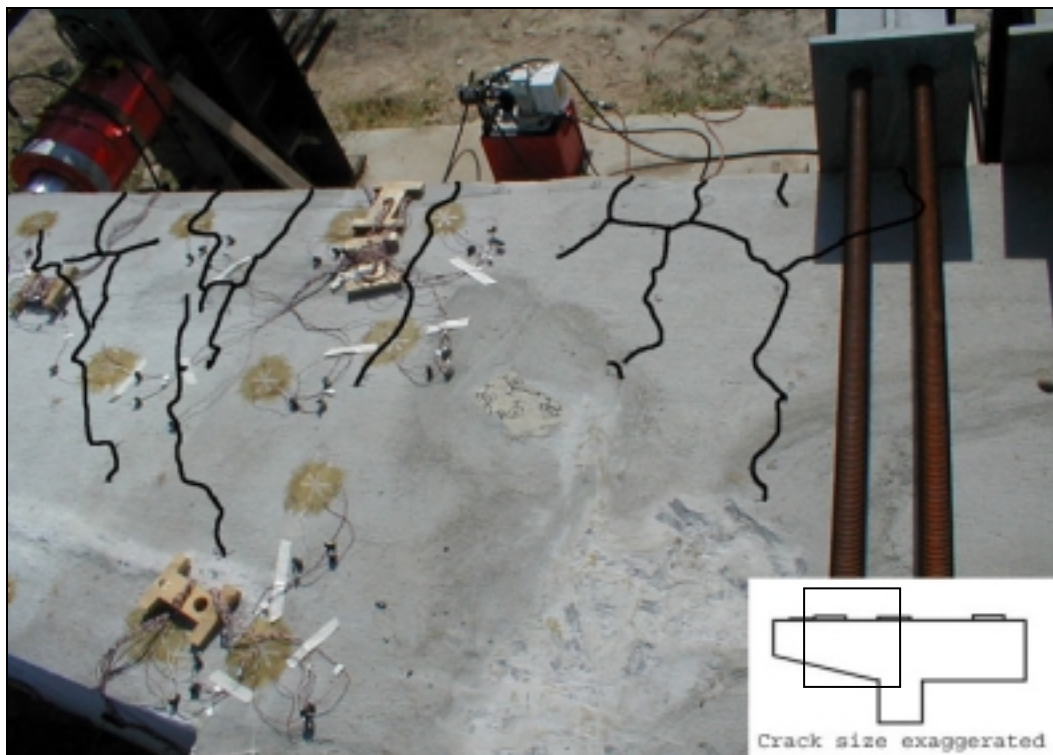


Figure 4.25 – Further propagation of cracks, cycle 6, Bent 15S

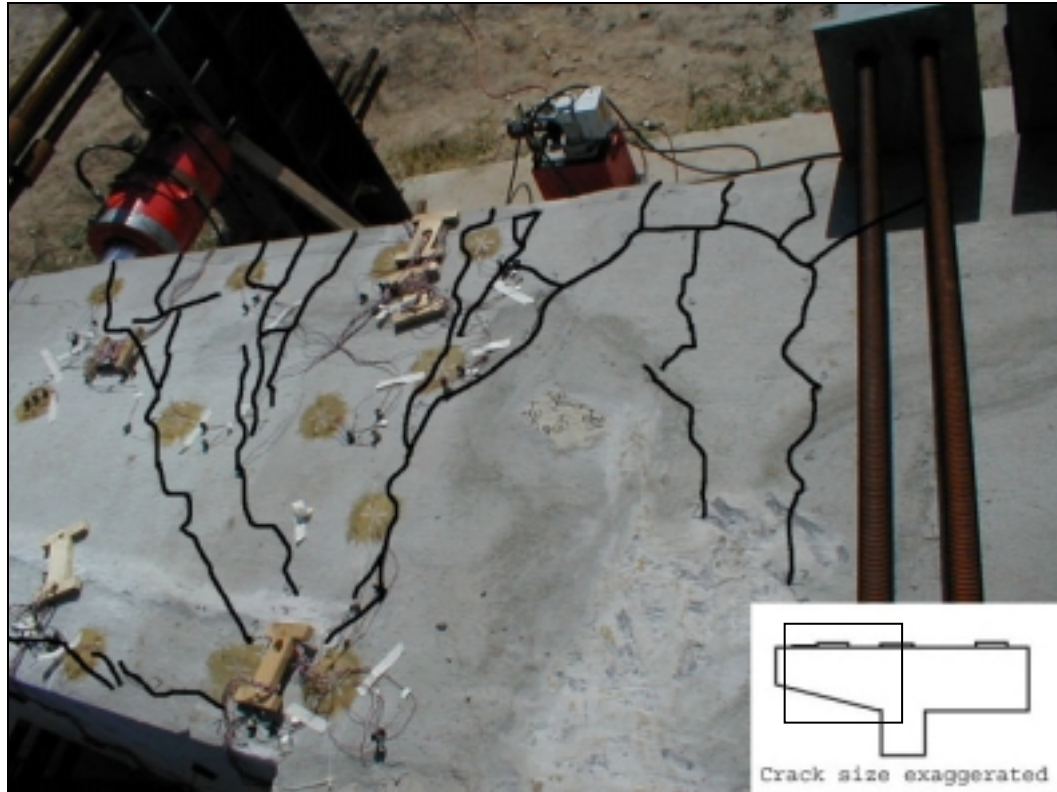


Figure 4.26 – Significant propagation of cracks, cycle 7, Bent 15S

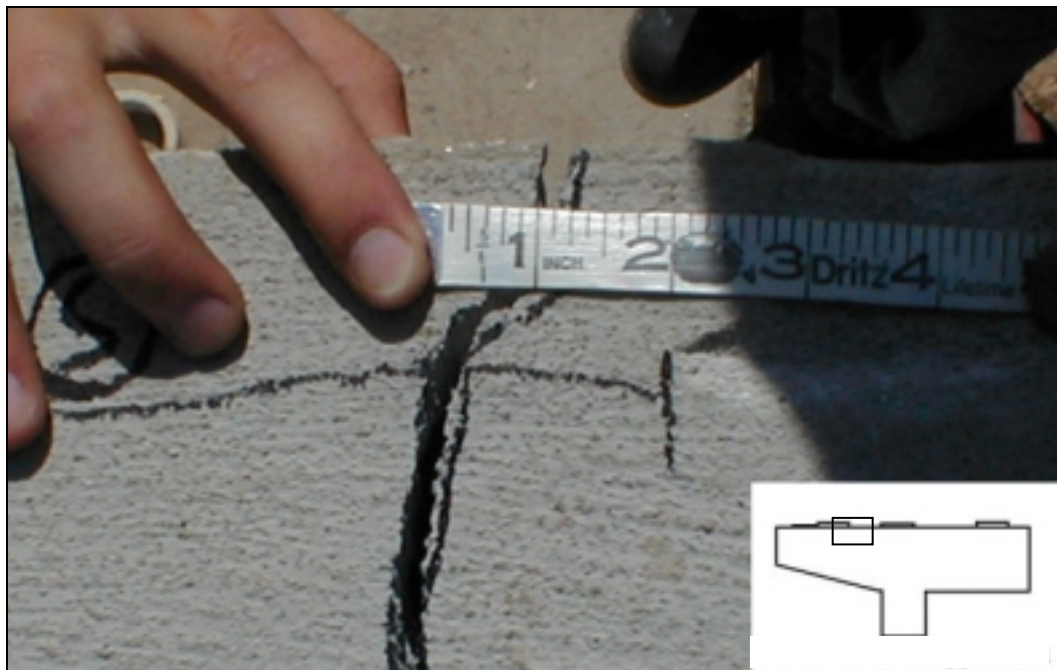


Figure 4.27 – Crack width of approximately 0.25 in (6 mm), cycle 7, Bent 15S



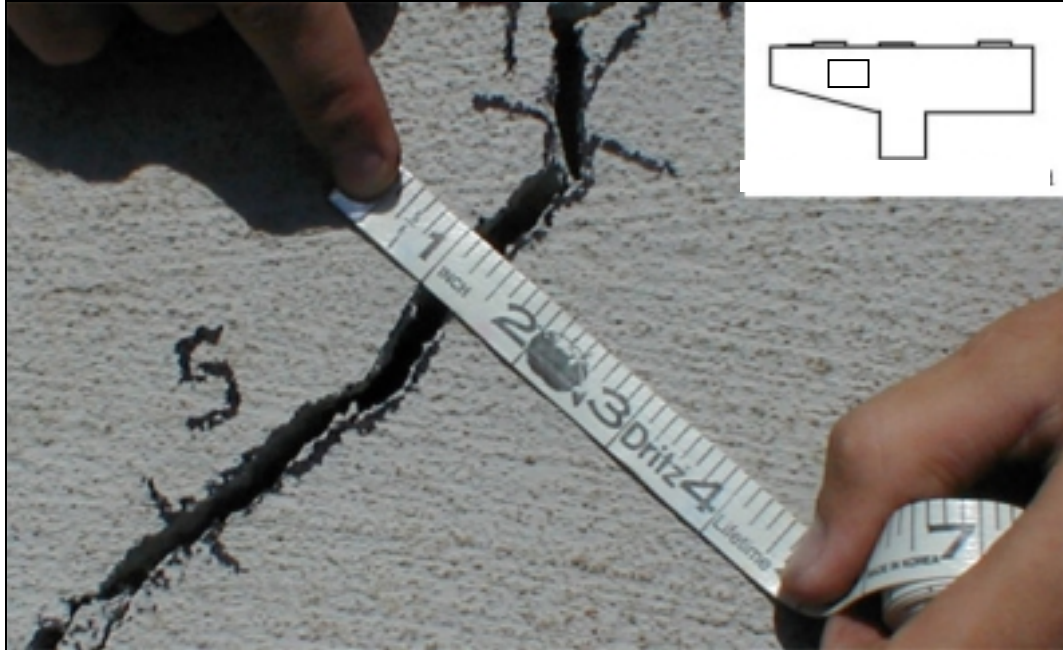


Figure 4.28 – Crack width of approximately 0.375 in (10 mm), cycle 7, Bent 15S

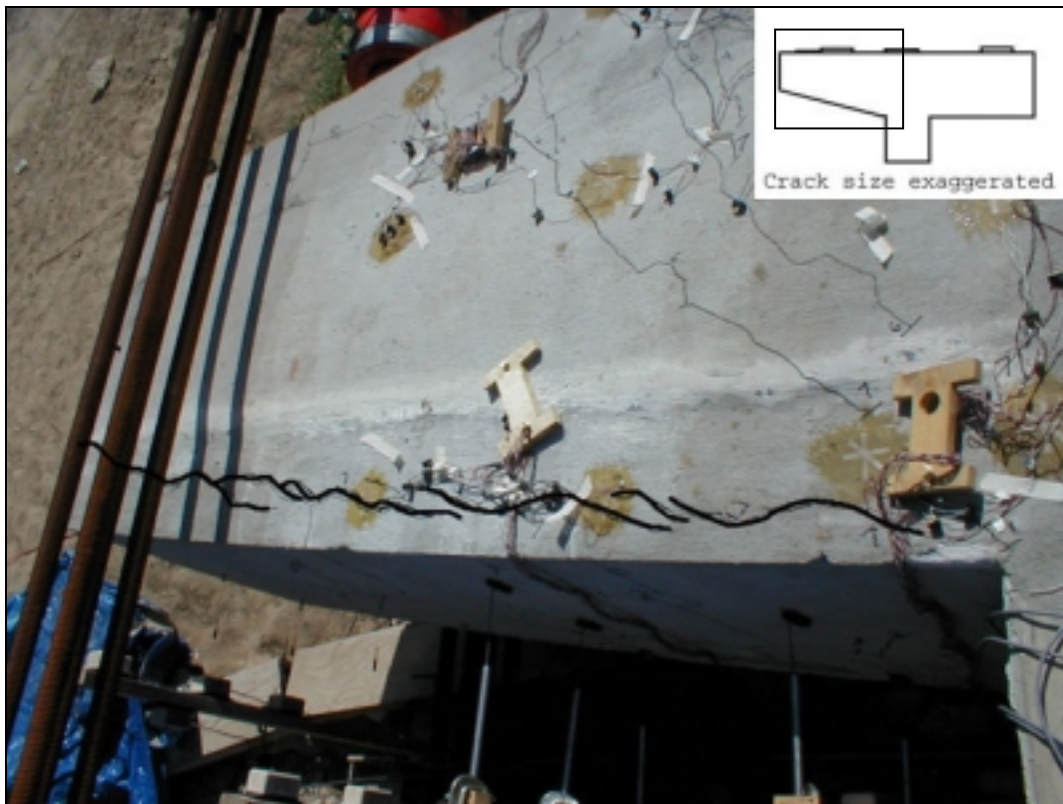


Figure 4.29 – Cracks along new and old concrete interface, west face, cycle 7



Figure 4.30 – Cracks along new and old concrete interface, east face, cycle 7



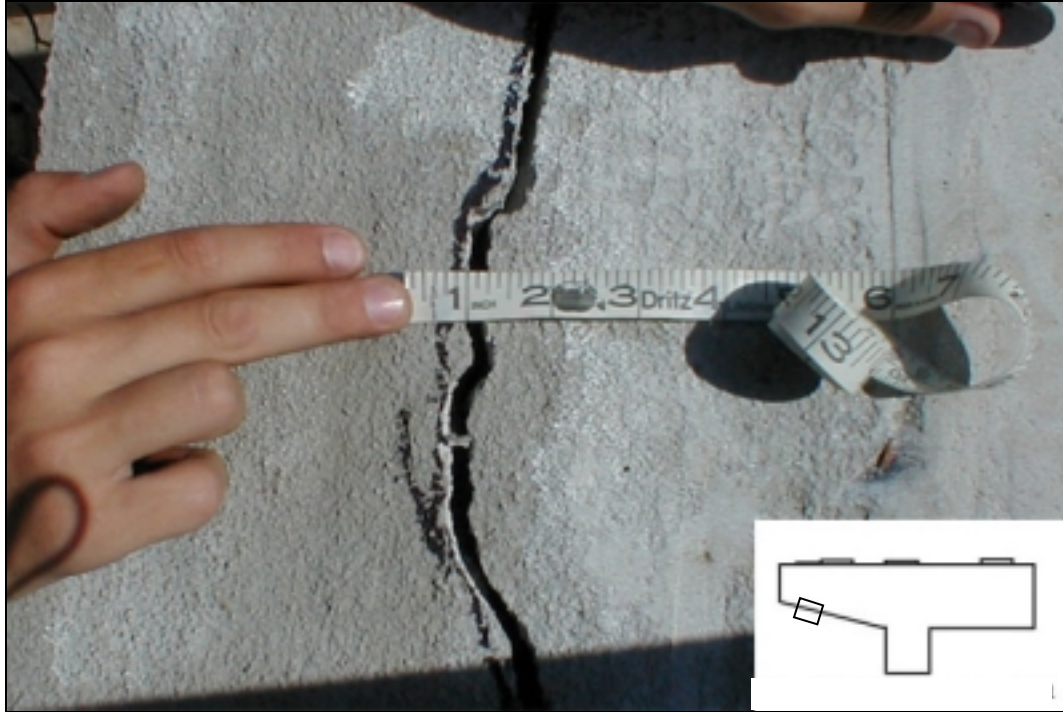


Figure 4.31 – Crack width of approximately 0.25 in (6 mm), cycle 7

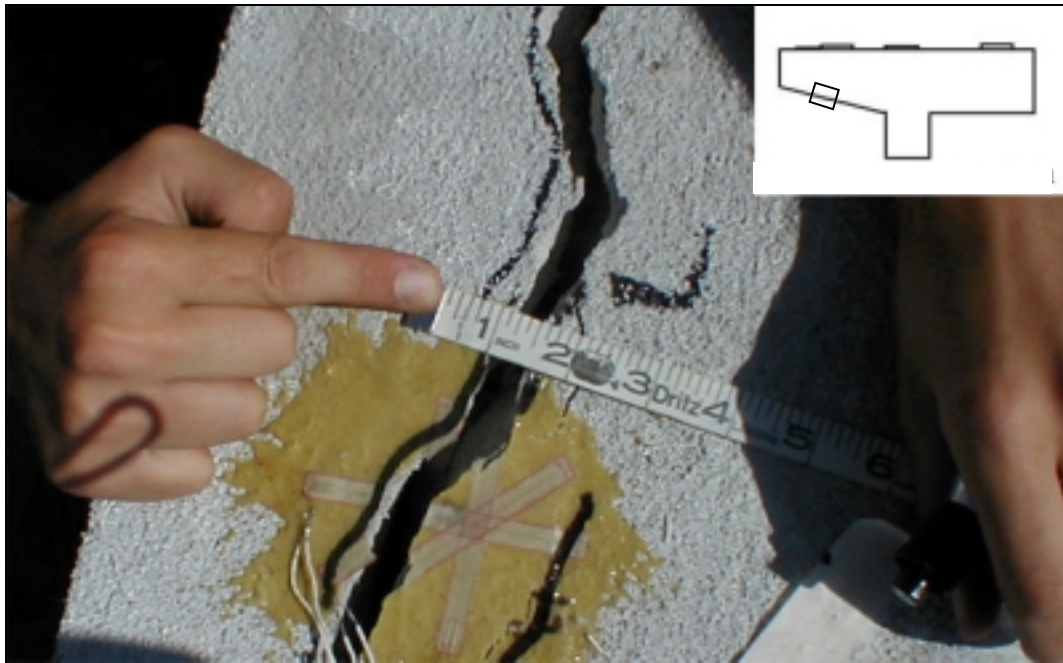


Figure 4.32 – Crack width of approximately 0.375 in (10 mm), cycle 7



Figure 4.33 – Crack width of approximately 0.5 in (13 mm), cycle 7

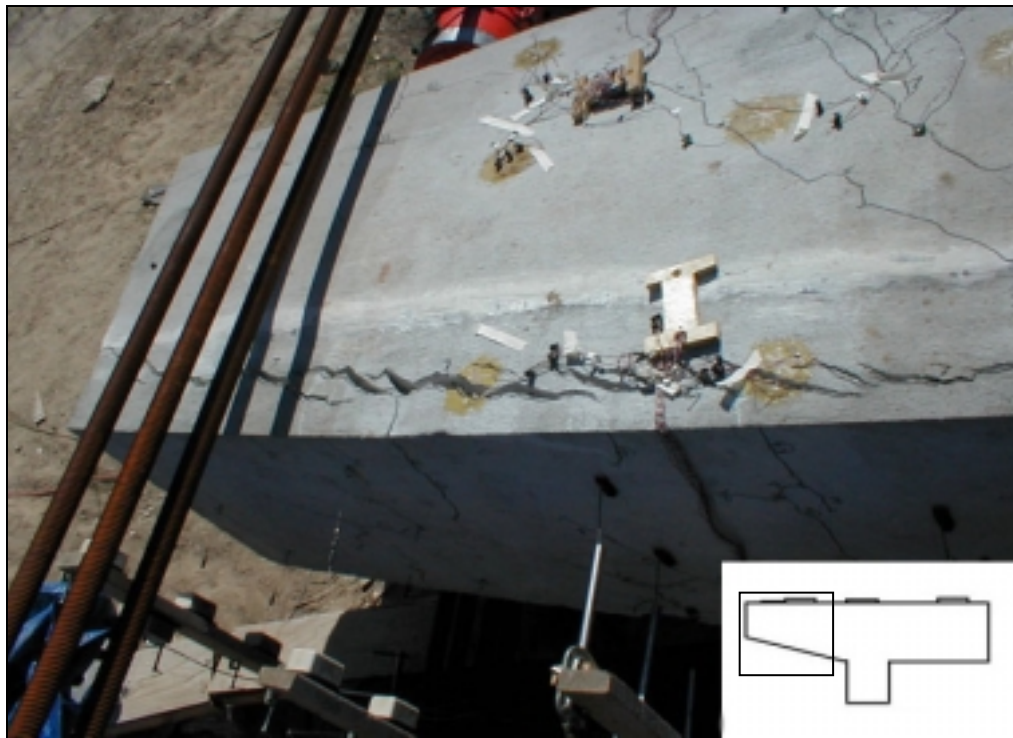


Figure 4.34 – Crack width of approximately 1 in (25 mm), cycle 8



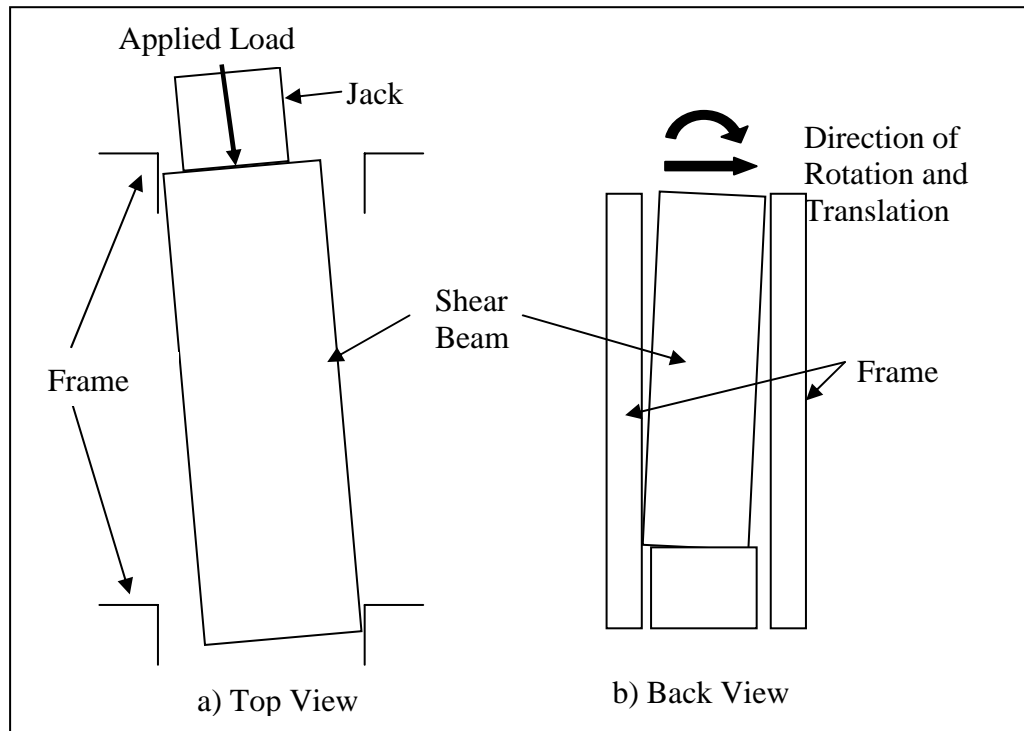


Figure 4.35 – Movement of Loading Frame



Figure 4.36 – Failure of the Loading Frame—Back View



Figure 4.37 – Failure of the Loading Frame—Side View



Figure 4.38 – Failure of the concrete patch



Figure 4.39 – Surface of old concrete—bonding agent showing





Figure 4.40 – Tip of the cantilever surface of old concrete—Bonding agent showing

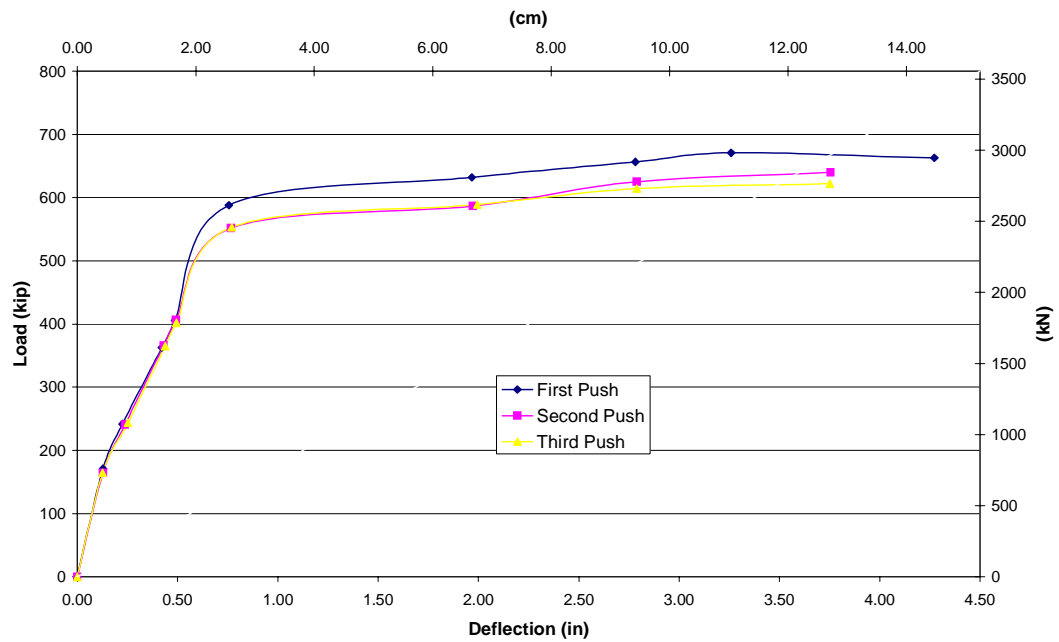


Figure 4.41 – Peak Loads of each push for Bent 2N

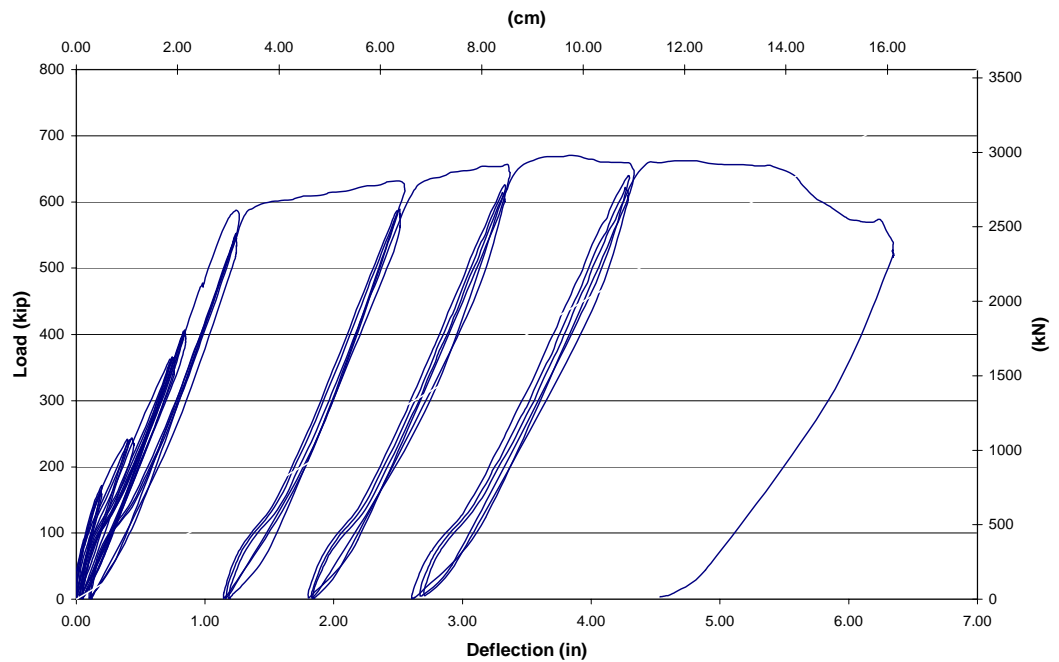


Figure 4.42 – Original Load vs. Deflection for Bent 2N



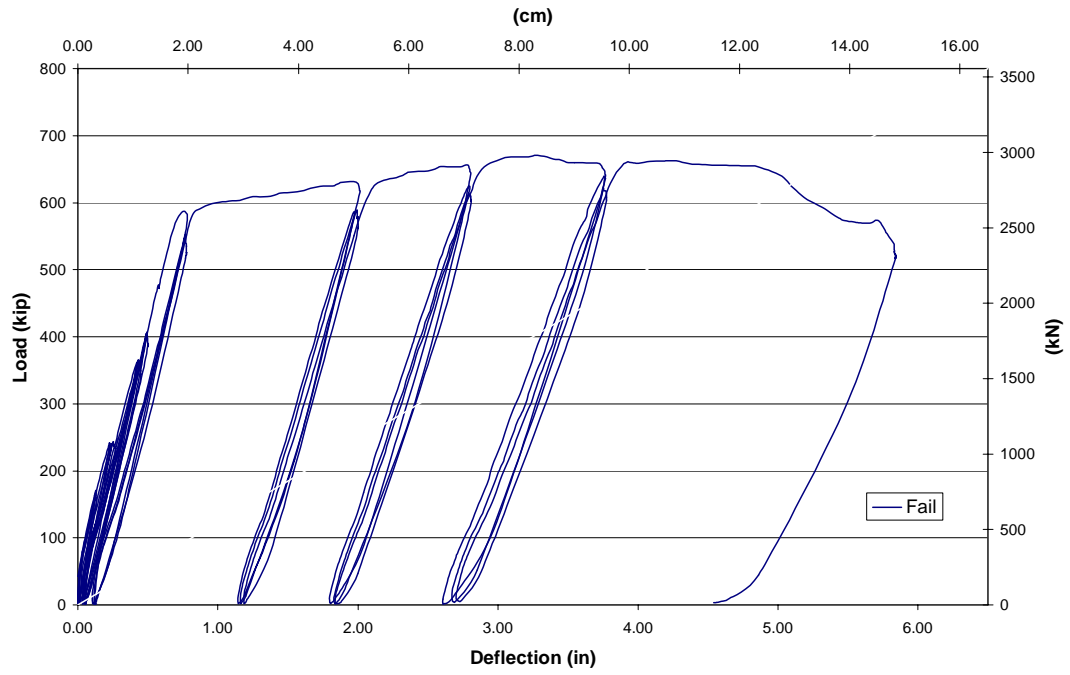


Figure 4.43 – Corrected Load vs. Deflection for Bent 2N

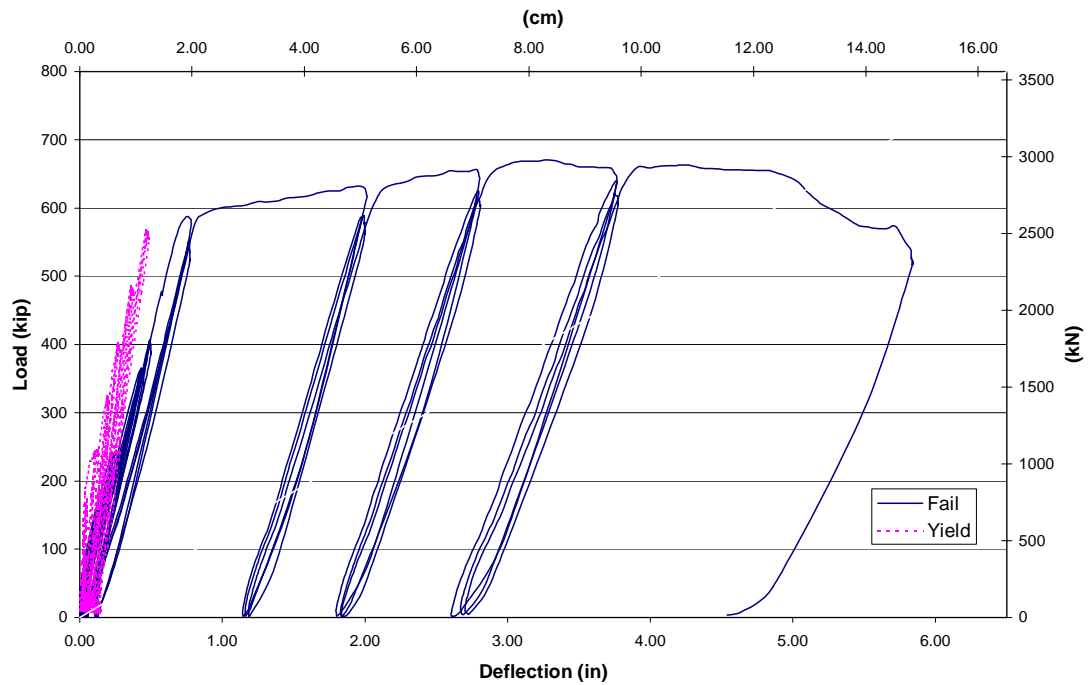


Figure 4.44 – Load vs. Deflection for Bent 2N (Yield and Failure Tests)

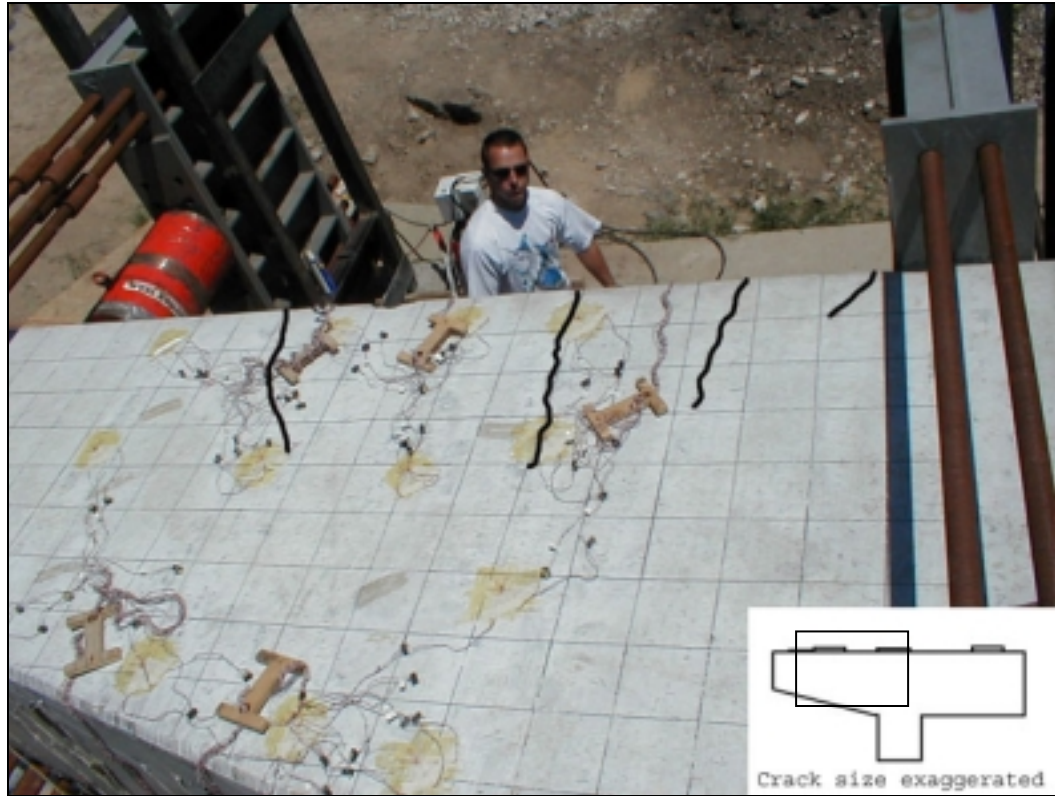


Figure 4.45 – Bent 2N, cracks on cycle 2

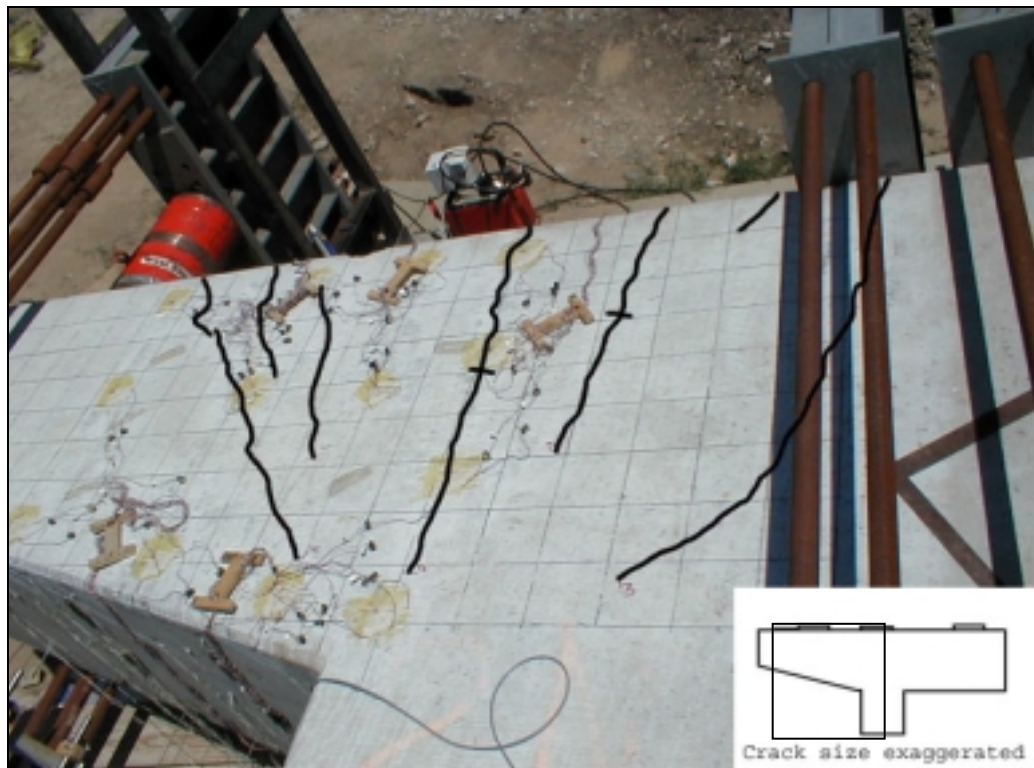


Figure 4.46 – Bent 2N, cracks on cycle 3

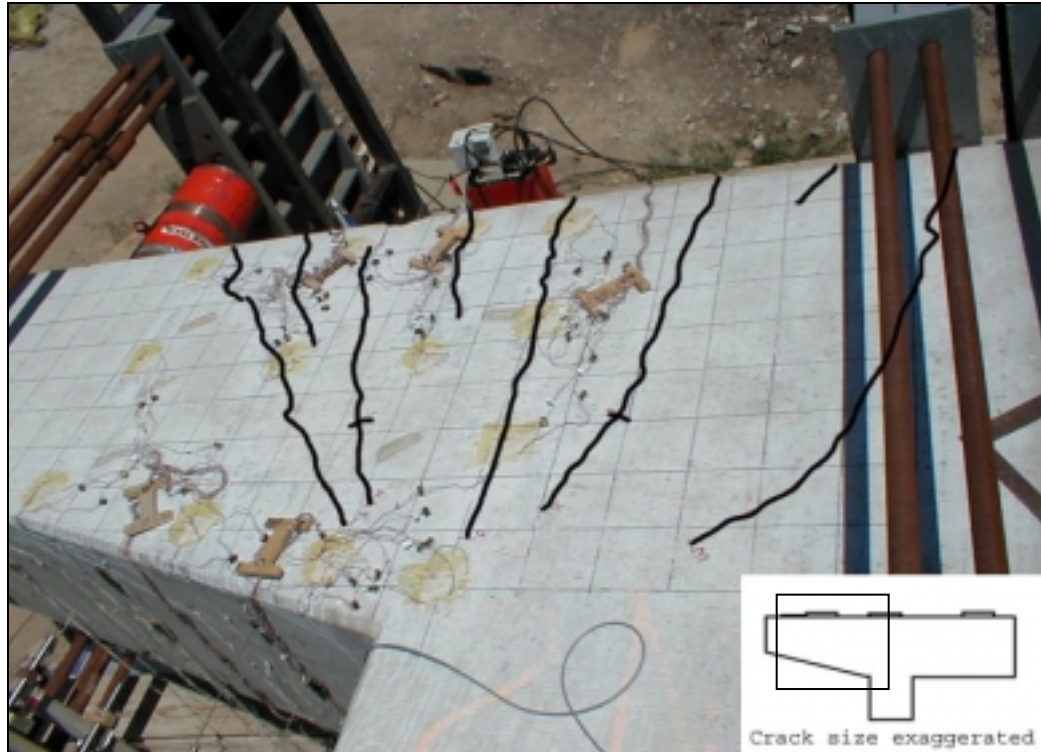


Figure 4.47 – Bent 2N, cracks on cycle 4



Figure 4.48 – Bent 2N, location of epoxy-injected cracks





Figure 4.49 – Bent 2N, cracks on cycle 6



Figure 4.50 – Bent 2N, cracks on top of bent, cycle 7



Figure 4.51 – Bent 2N, cracks on cycle 7

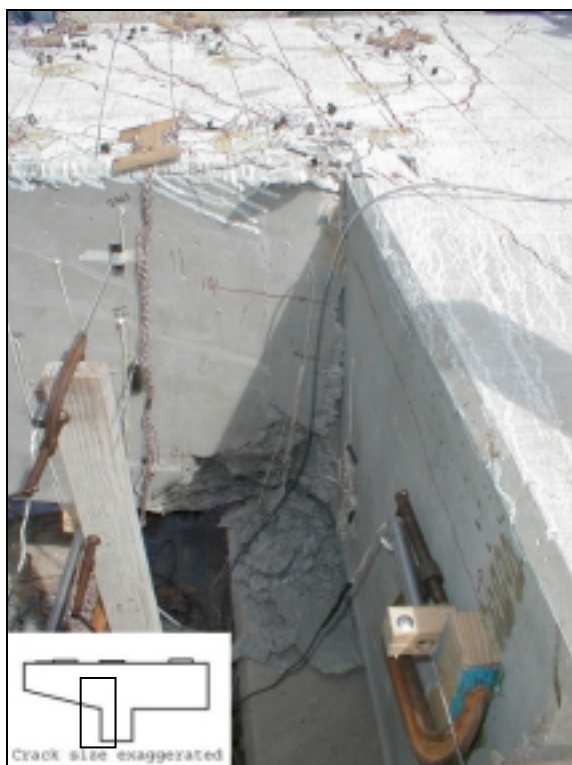


Figure 4.52 – Concrete failure—cycle 10



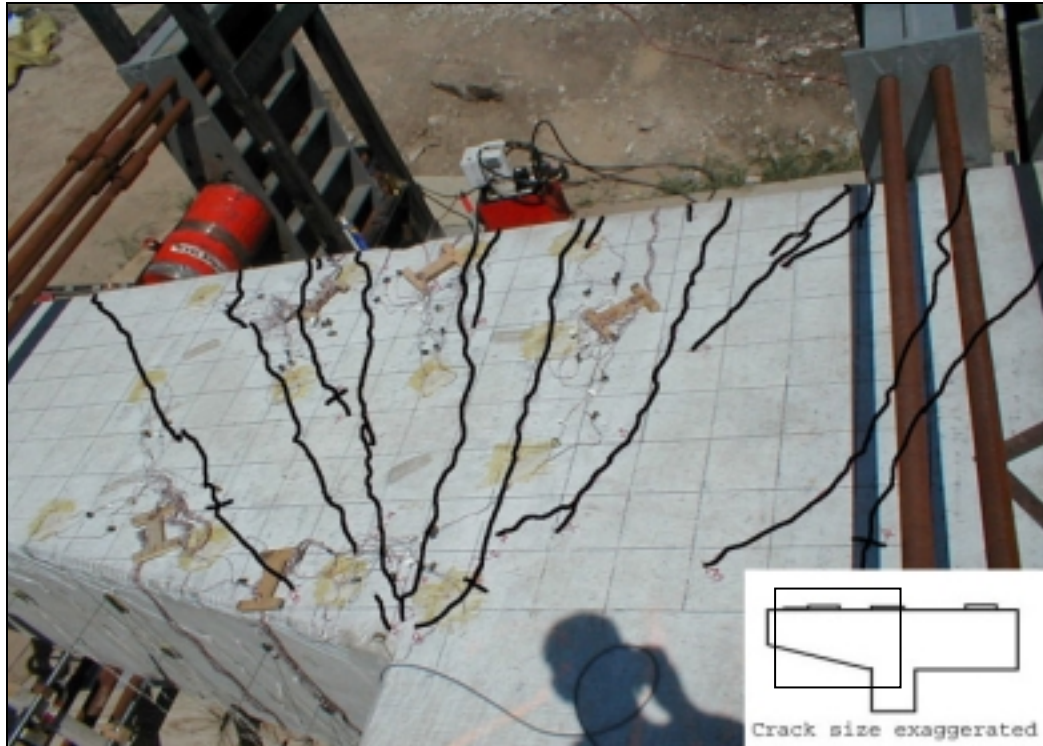


Figure 4.53 – Bent 2N, cracks on cycle 8



Figure 4.54 – Bent 2N, cracks on cycle 9

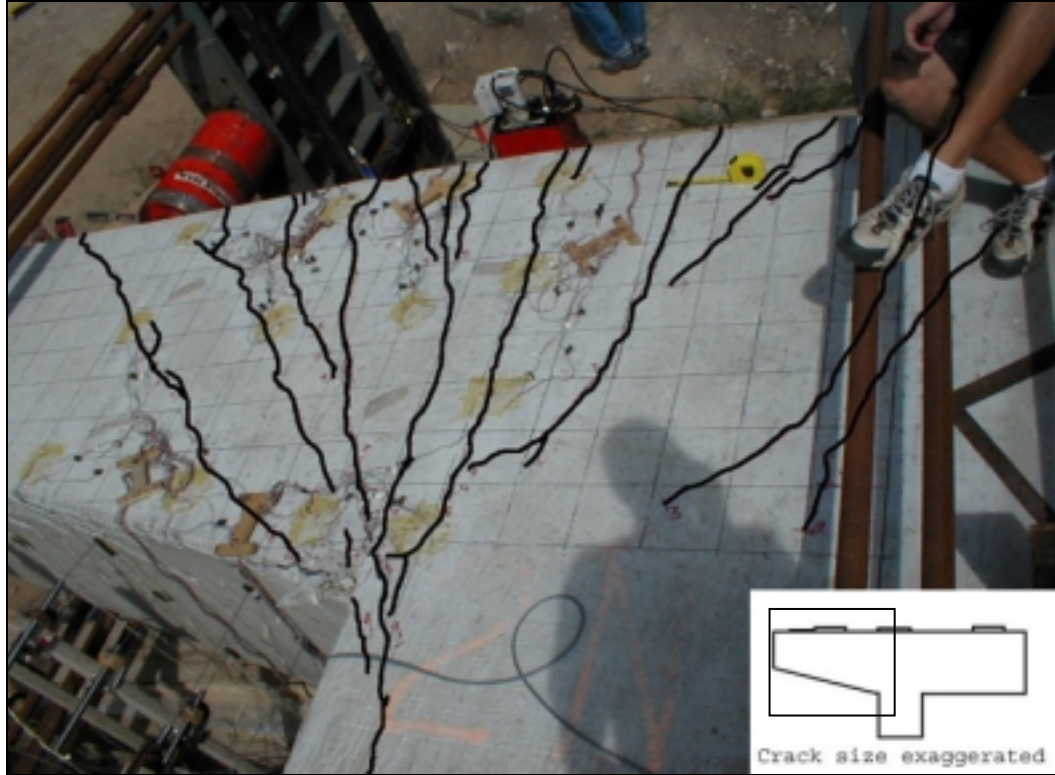


Figure 4.55 – Bent 2N, cracks on cycle 10, cross-section



Figure 4.56 – Bent 2N, cracks on cycle 10, top





Figure 4.57 – Crack 0.375 in (10 mm) wide—cycle 10, Bent 2N



Figure 4.58 – Crack 0.5 in (13 mm) wide—cycle 10, Bent 2N

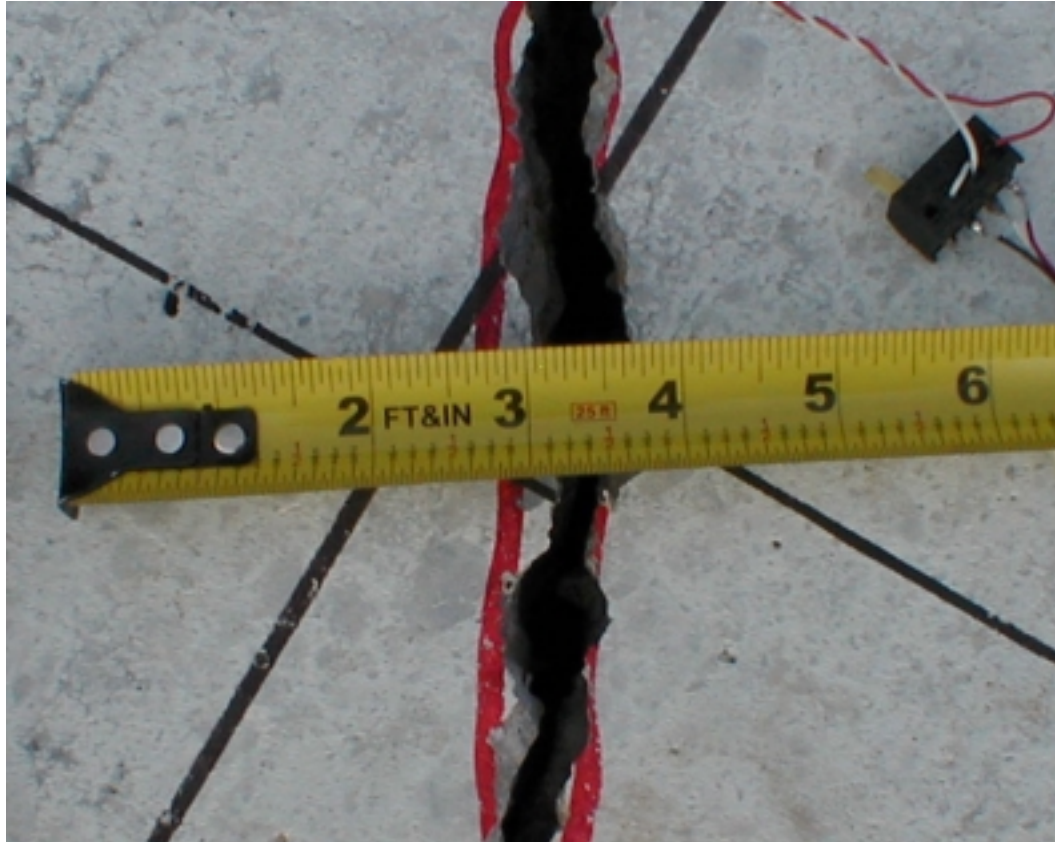


Figure 4.59 – Crack 0.688 in (17 mm) wide— cycle 10, Bent 2N

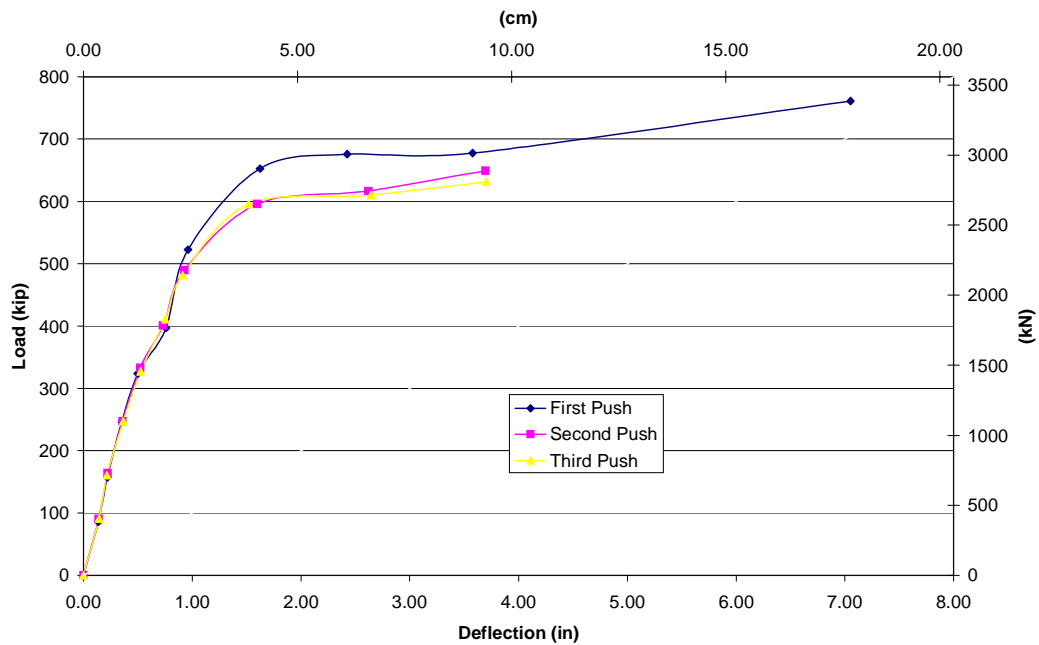


Figure 4.60 – Stiffness of each push for Bent 12N

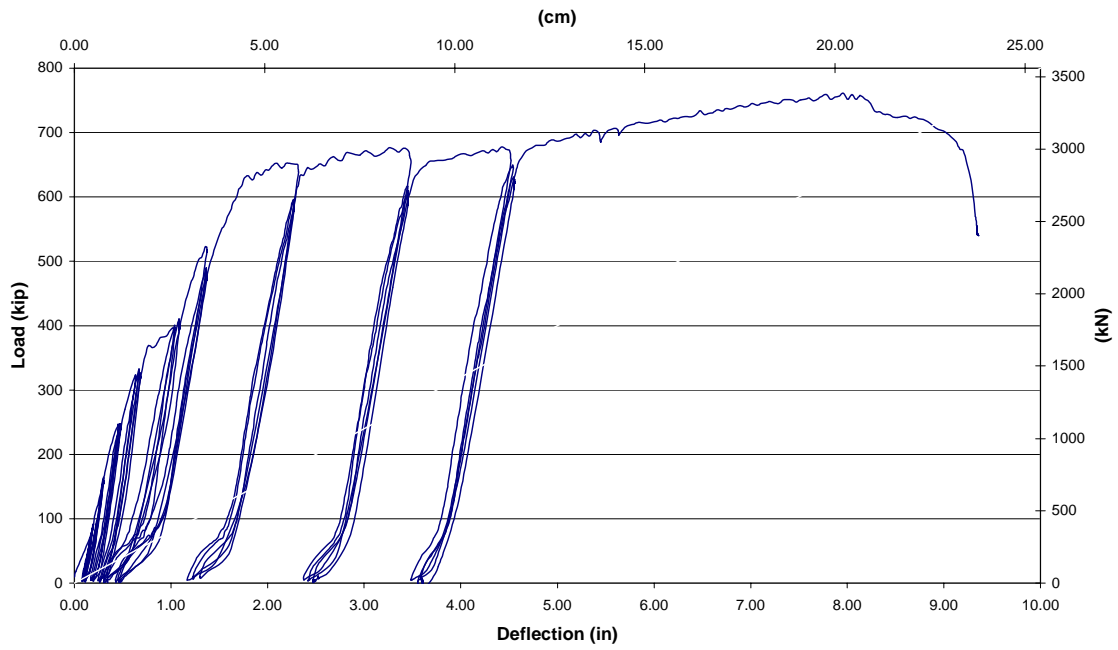


Figure 4.61 – Original Load vs. Deflection for Bent 12N

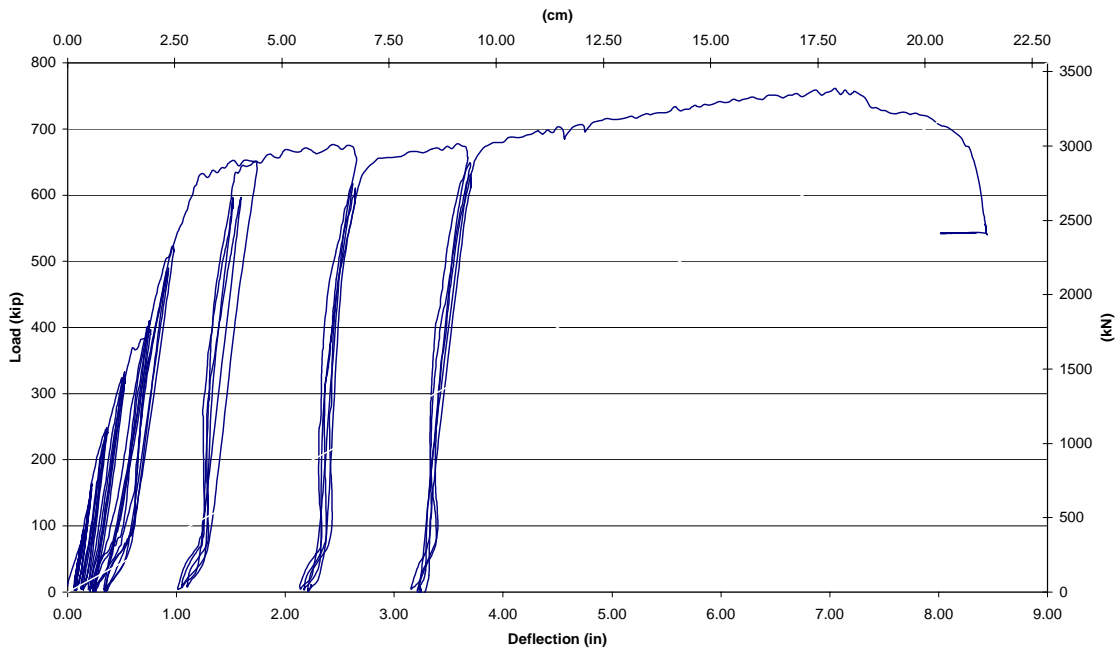


Figure 4.62 – Corrected Load vs. Deflection for Bent 12N



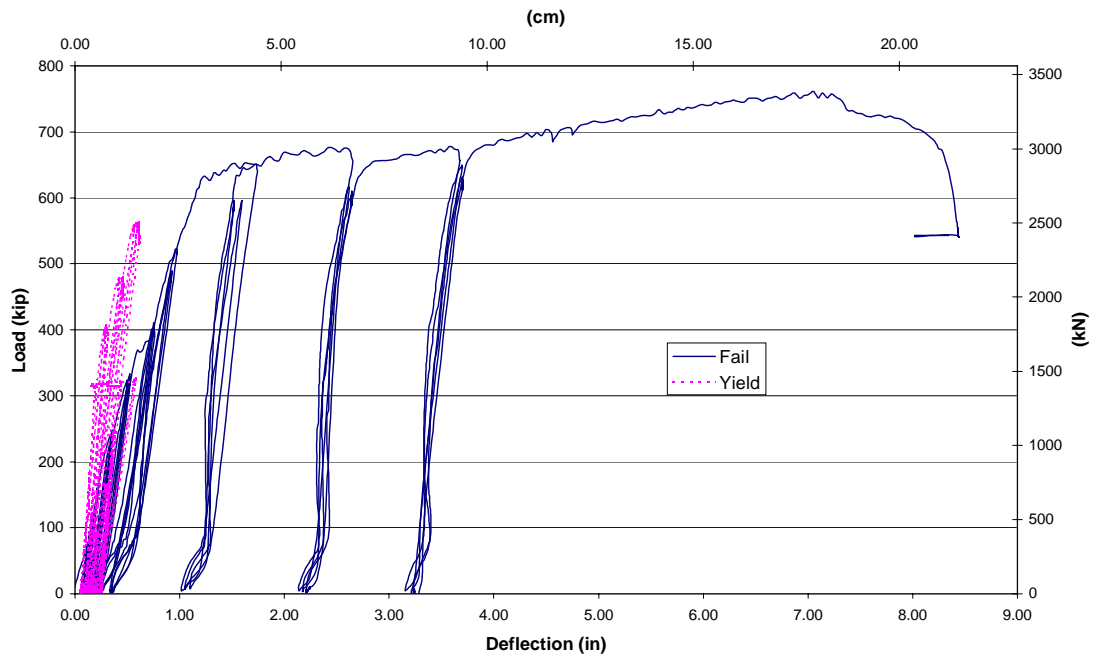


Figure 4.63 – Load vs. Deflection for Bent 12N (Yield and Failure)



Figure 4.64 – Bent 12N, cracks on cycle 3



Figure 4.65 – Bent 12N, crack at base of column—cycle 3



Figure 4.66 – Bent 12N, cracks on cycle 4



Figure 4.67 – Bent 12N, cracks on cycle 5



Figure 4.68 – Bent 12N, cracks on cycle 6





Figure 4.69 – Bent 12N, crack in column on cycle 6

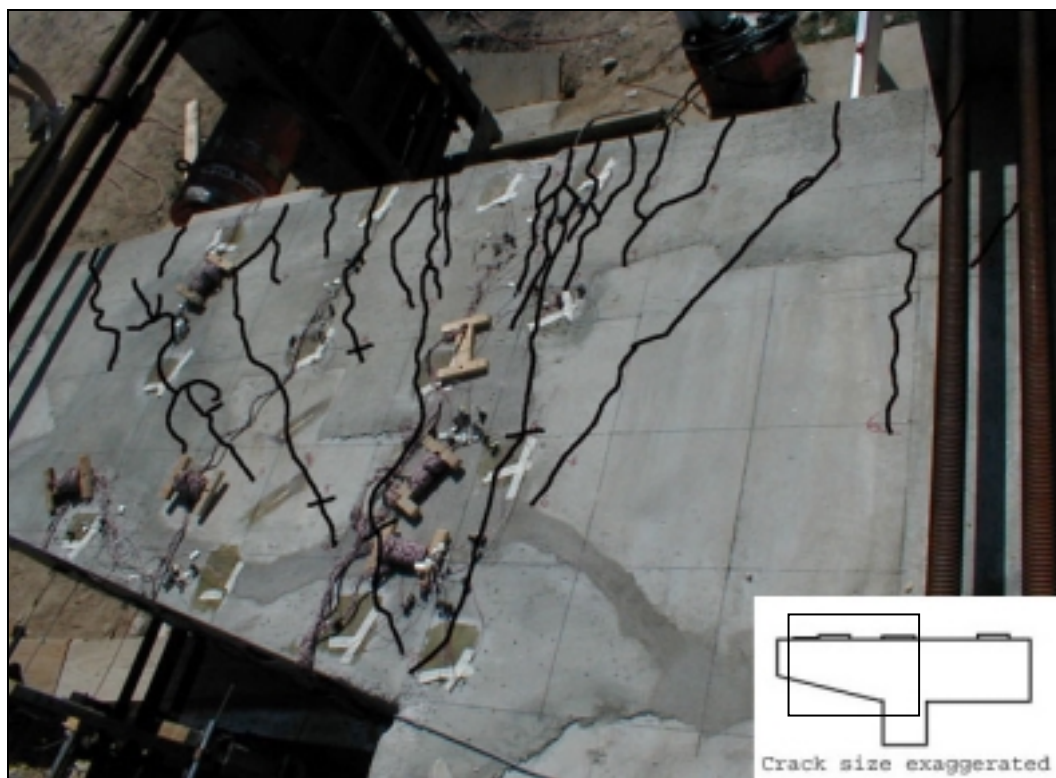


Figure 4.70 – Bent 12N, cracks on cycle 7



Figure 4.71 – Bent 12N, cracks on cycle 8





Figure 4.72 – Bent 12N, cracks on cycle 9

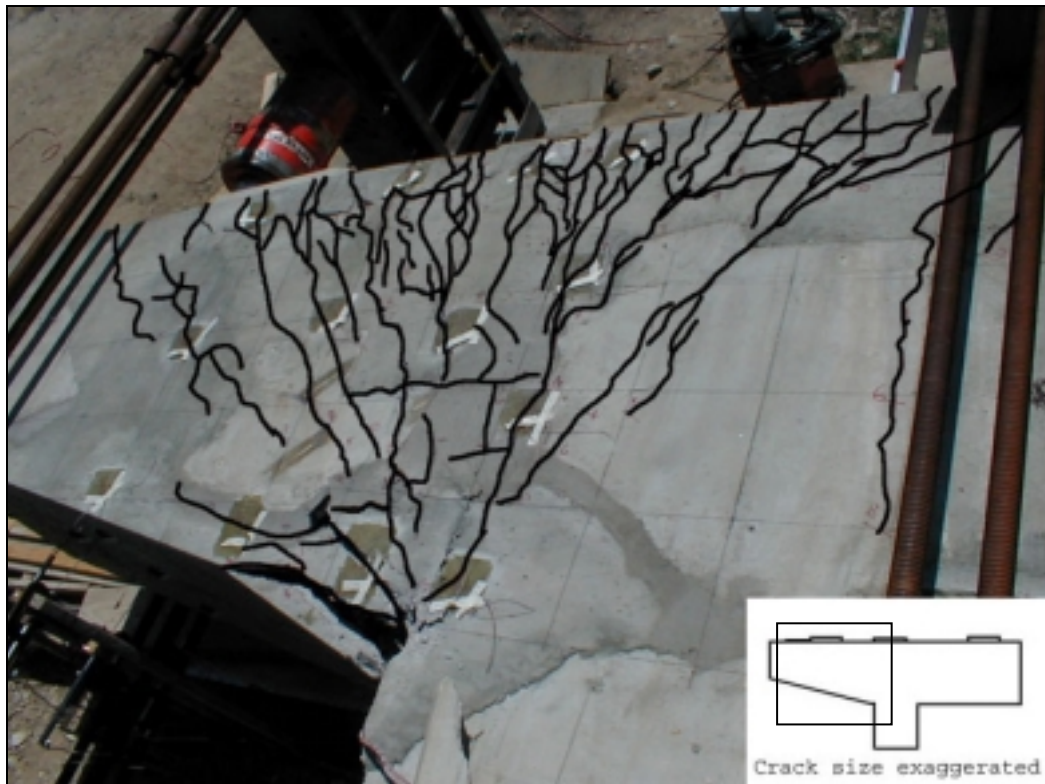


Figure 4.73 – Bent 12N, well distributed crack pattern—cycle 10



Figure 4.74 – Bent 12N, crushing at compression zone—bottom of cantilever



Figure 4.75 – Bent 12N, crushing at compression zone—top view



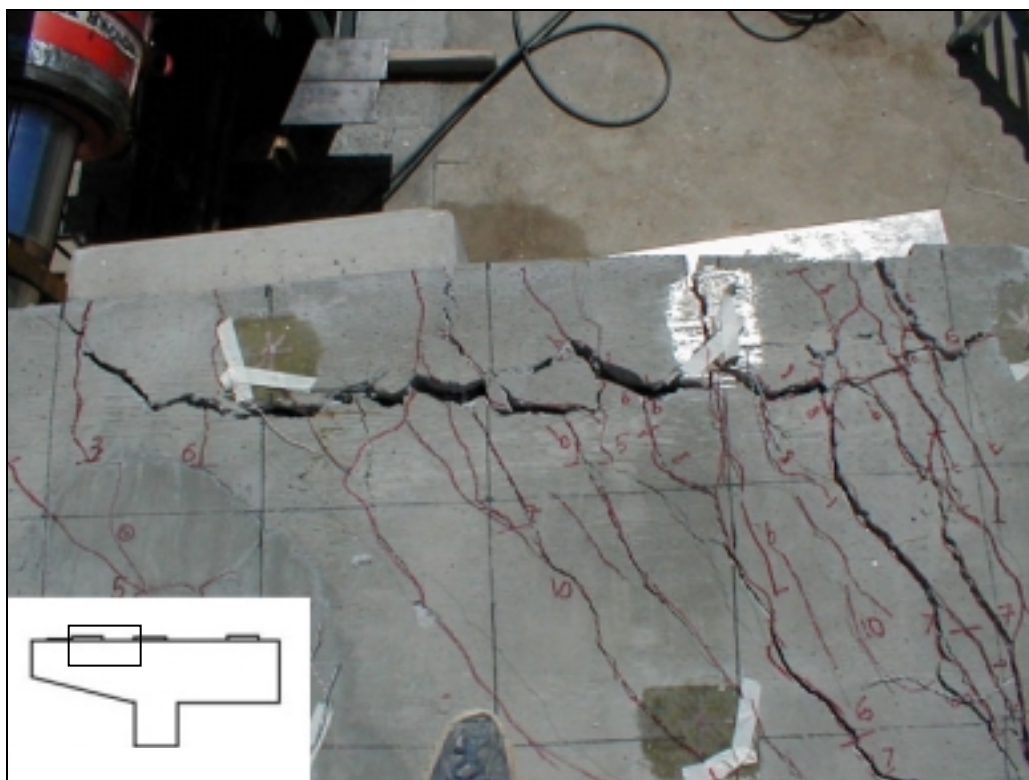


Figure 4.76 – Bent 12N, crack along main reinforcing steel



Figure 4.77 – Existing crack along main reinforcing steel (Rowe, 2001)

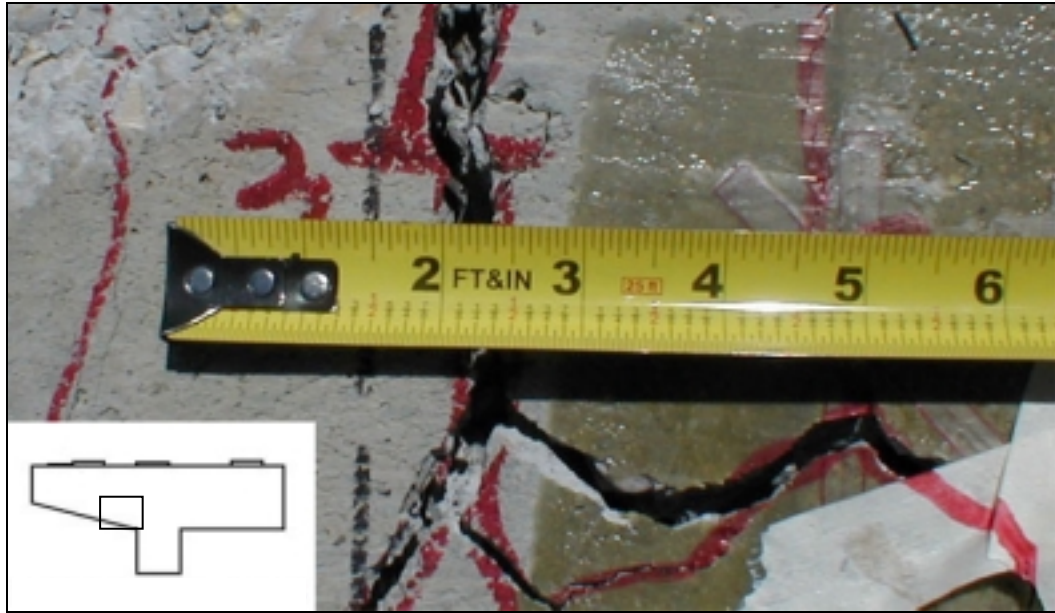


Figure 4.78 – Bent 12N, crack 0.25 in (6 mm) wide—cycle 10



Figure 4.79 – Bent 12N, crack 1 in (25 mm) wide—cycle 10





Figure 4.80 – Bent 12N, crack 0.75 in (19 mm) wide—cycle 10





Figure 4.81 – Permanent displacement of Bent 12N

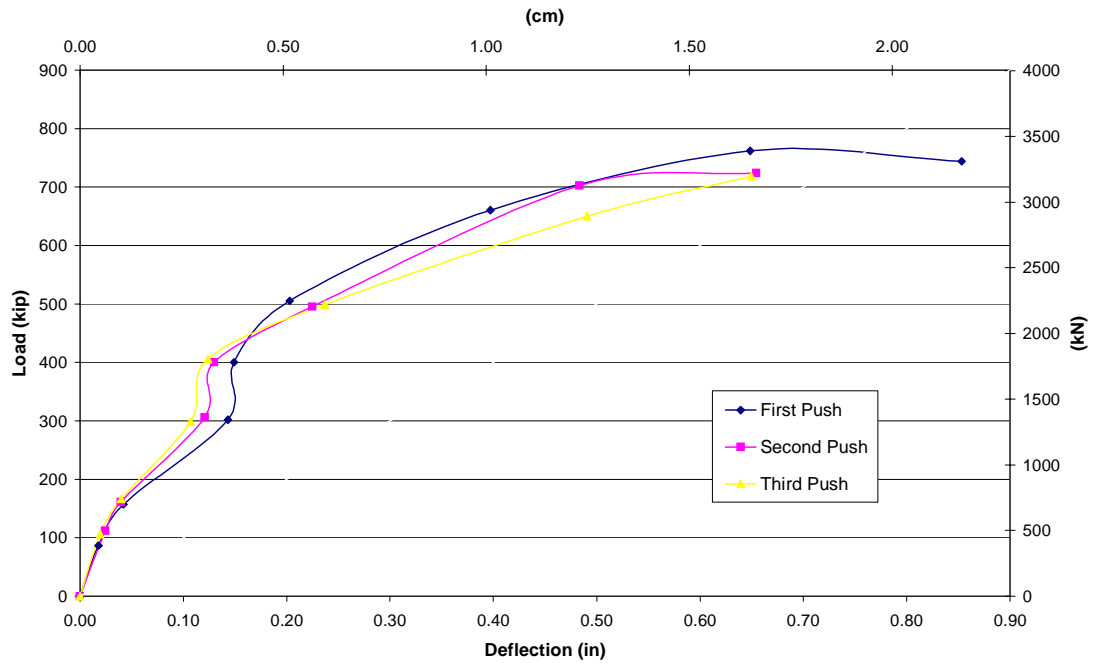


Figure 4.82 – Peak Loads of each push for Bent 13S

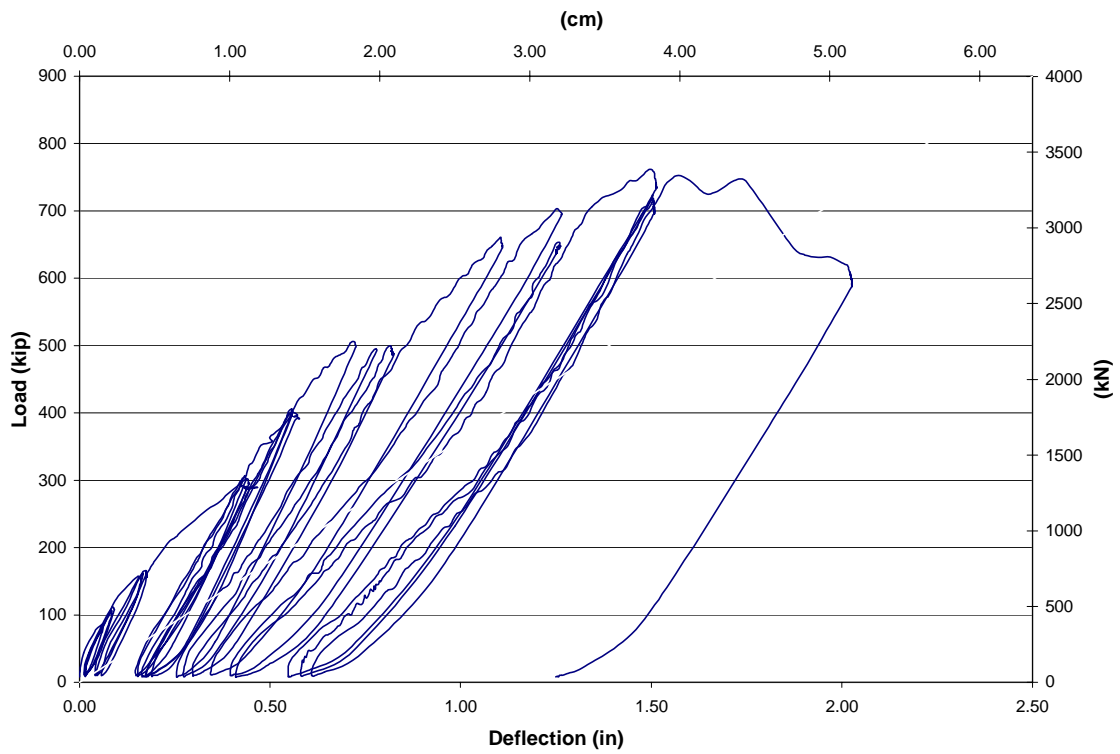


Figure 4.83 – Original Load vs. Deflection for Bent 13S

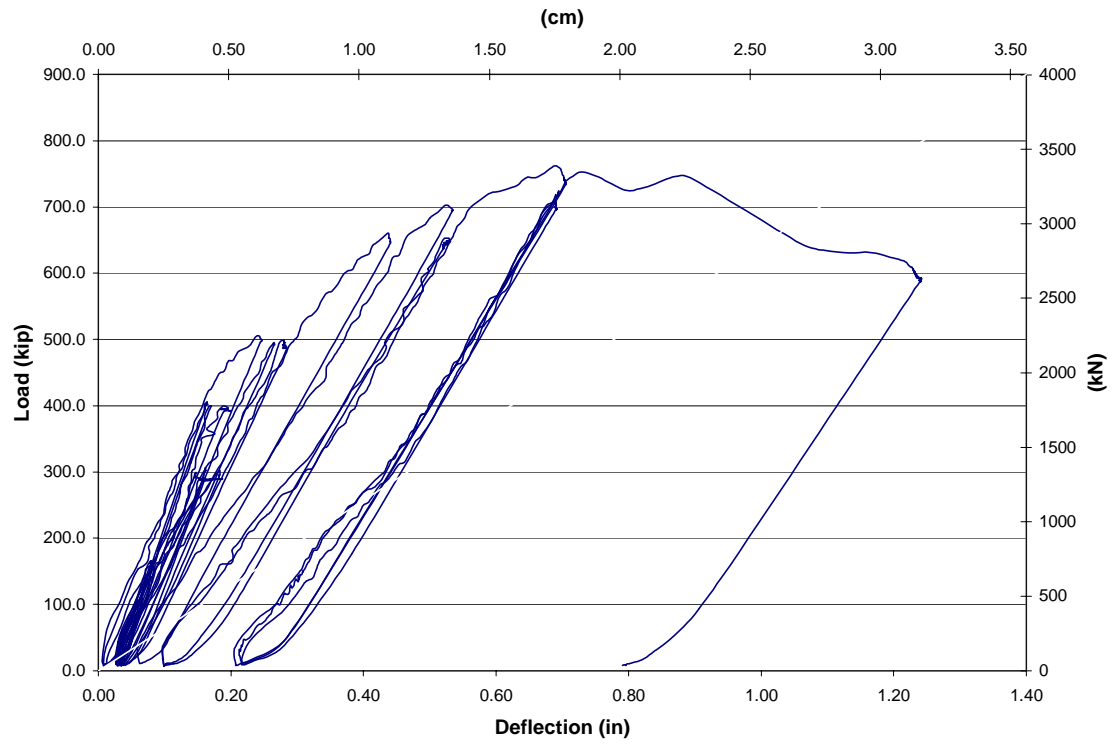


Figure 4.84 – Corrected Load vs. Deflection for Bent 13S

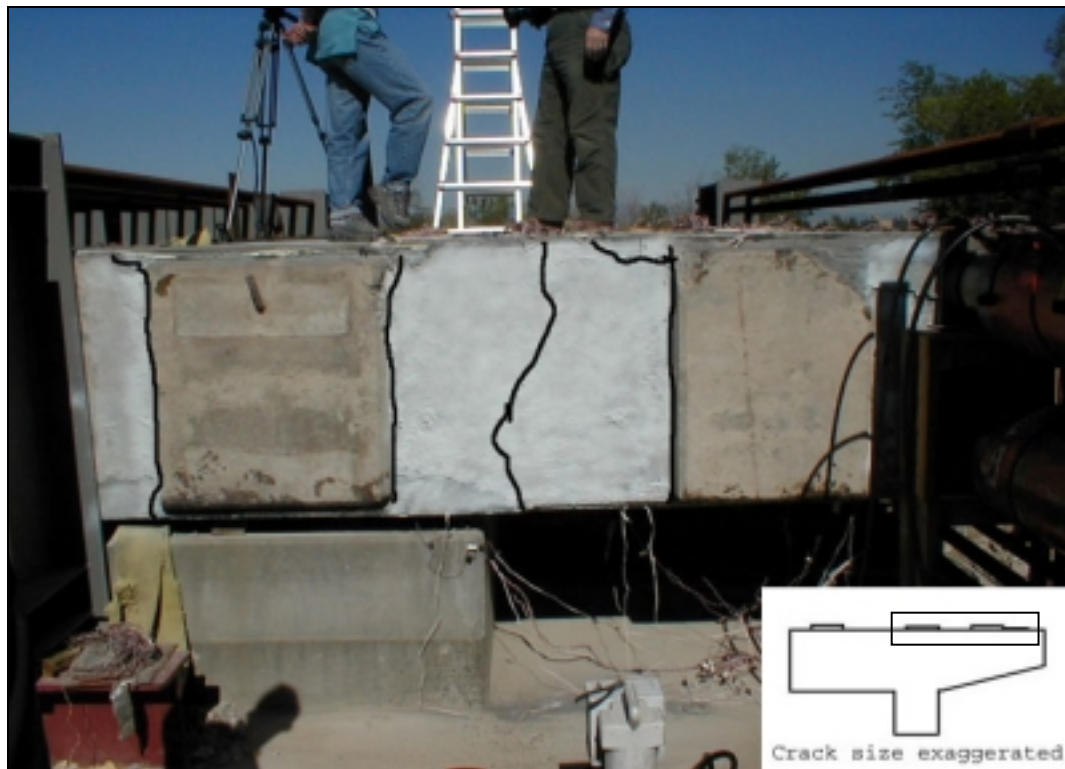


Figure 4.85 – Bent 13S, cracks on cycle 5



Figure 4.86 – Bent 13S, cracks on cycle 6 (black = new; white = shrinkage)



Figure 4.87 – Bent 13S, cracks on cycle 7 (black = new; white = shrinkage)





Figure 4.88 – Bent 13S, debonding between concrete and CFRP on cycle 7



Figure 4.89 – Bent 13S, close up of the debonded region



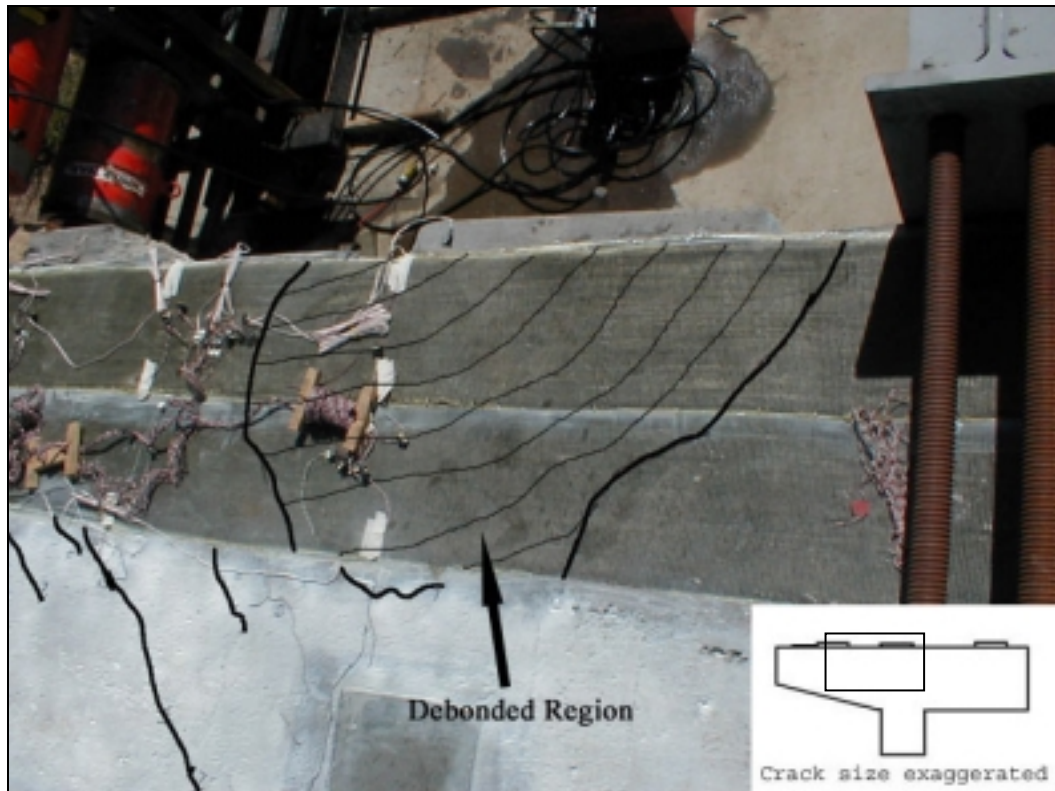


Figure 4.90 – Bent 13S, debonded region between concrete and CFRP on cycle 7



Figure 4.91 – Ben13S, debonding of wrap—overall view



Figure 4.92 – Bent 13S, close up of debonded region



Figure 4.93 – Bent 13S, complete failure of CFRP



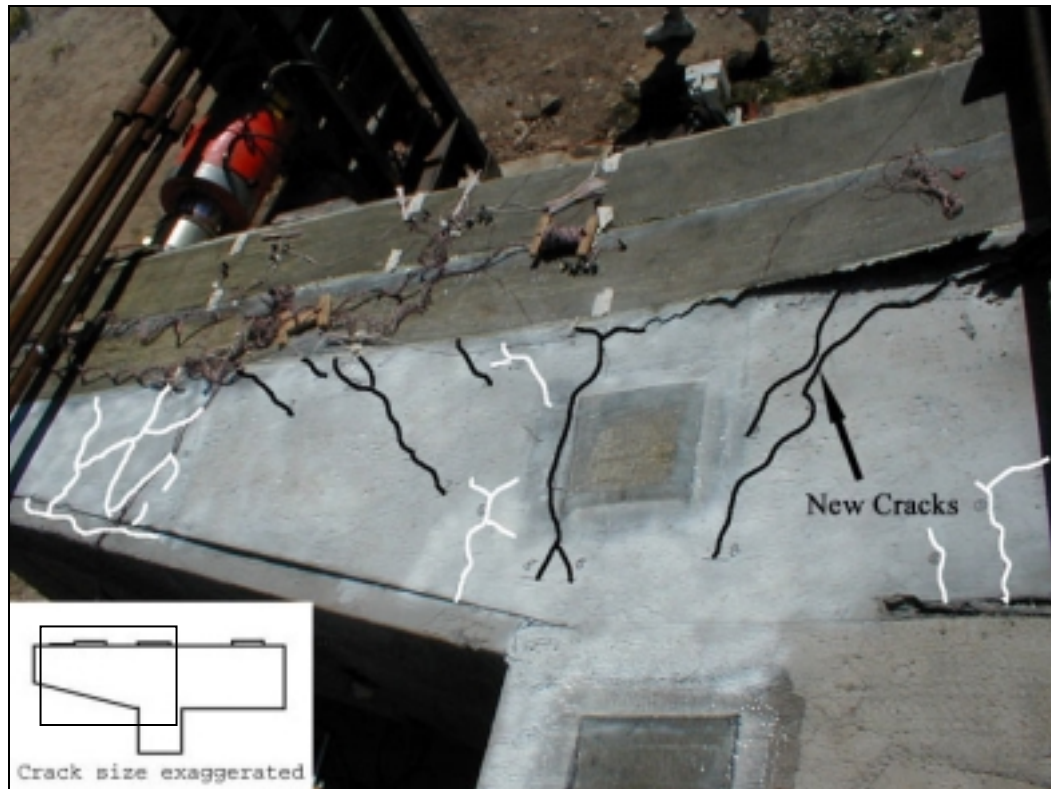


Figure 4.94 – Bent 13S, new cracks observed at failure



Figure 4.95 – Bent 13S, new cracks in the middle of the pedestal



Figure 4.96 – Bent 13S, debonding of CFRP wraps at failure (cycle 8)



Figure 4.97 – Bent 13S, crack 0.375 in (13 mm) wide—cycle 8



Figure 4.98 – Bent 13S, compression zone—no crushing at failure (cycle 8)



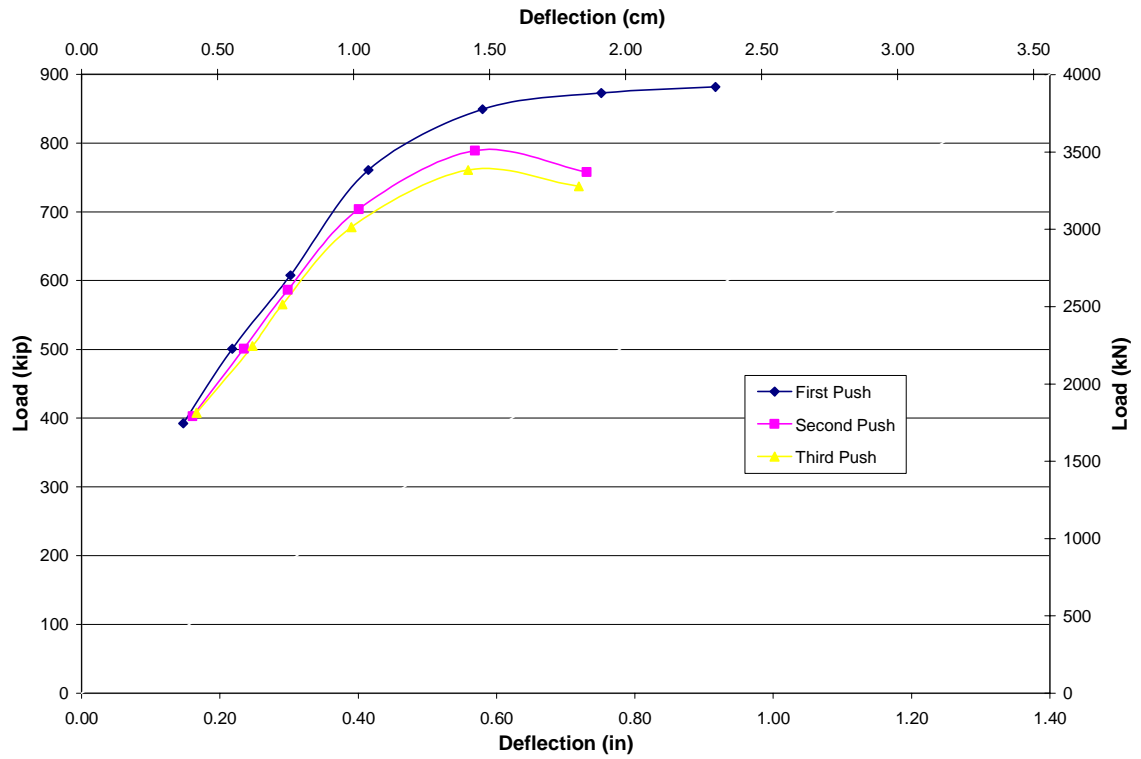


Figure 4.99 – Peak Loads of each push for Bent 13N

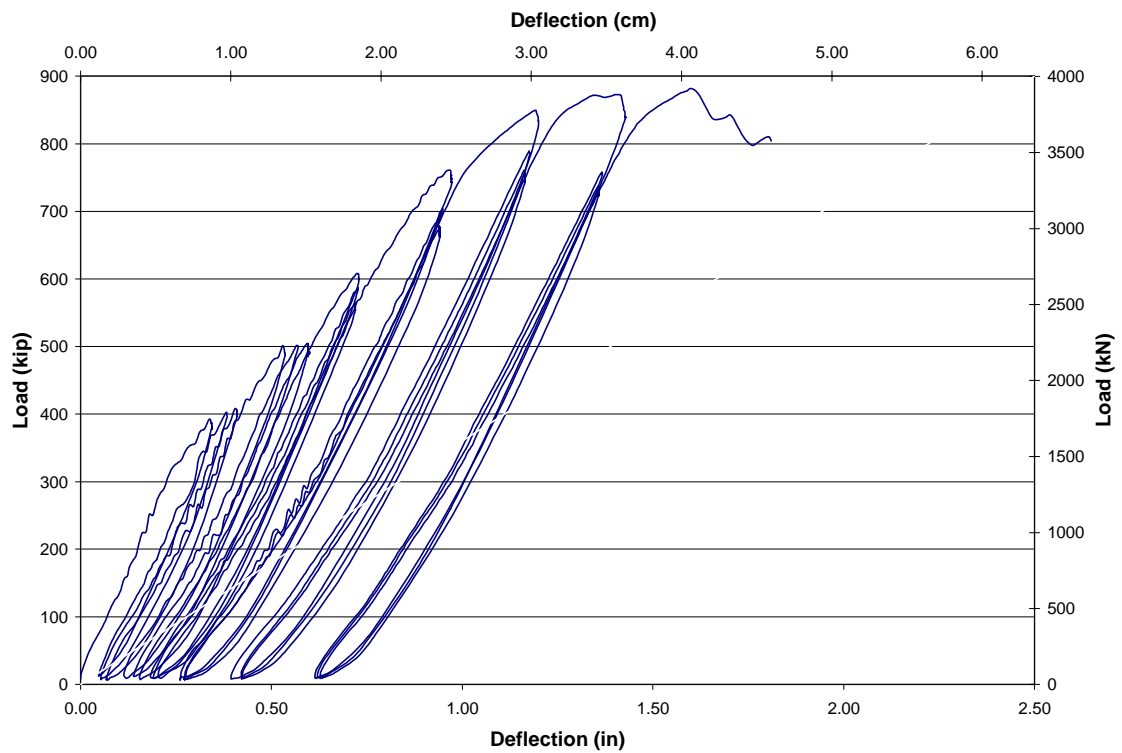


Figure 4.100 – Original Load vs. Deflection for Bent 13N

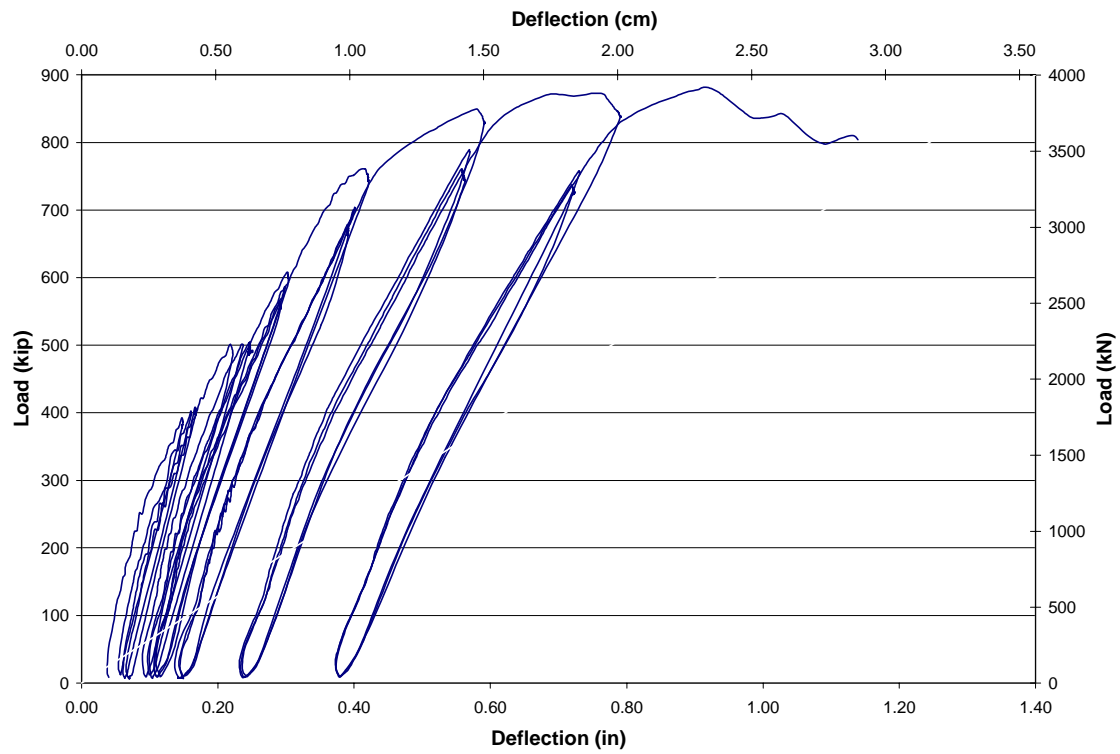


Figure 4.101 – Corrected Load vs. Deflection for Bent 13N

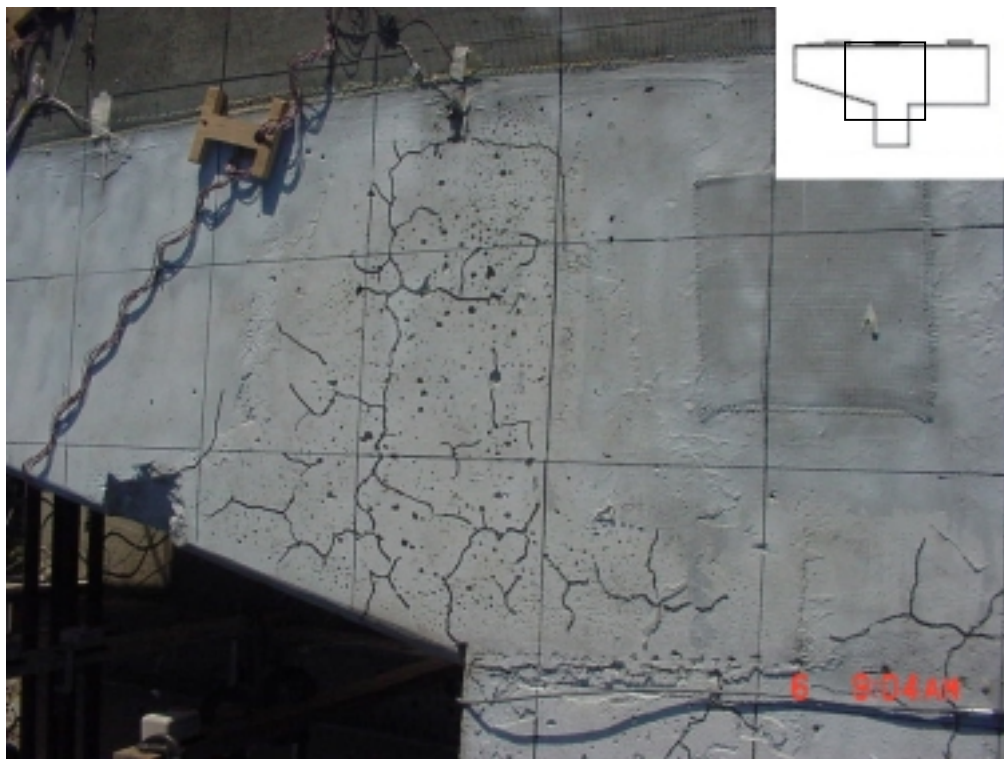


Figure 4.101a – Bent 13N, shrinkage cracking, side



Figure 4.102 – Bent 13N, shrinkage cracking, top



Figure 4.103 – Bent 13N, cracks after cycle 3



Figure 4.104 – Bent 13N, cracks after cycle 4

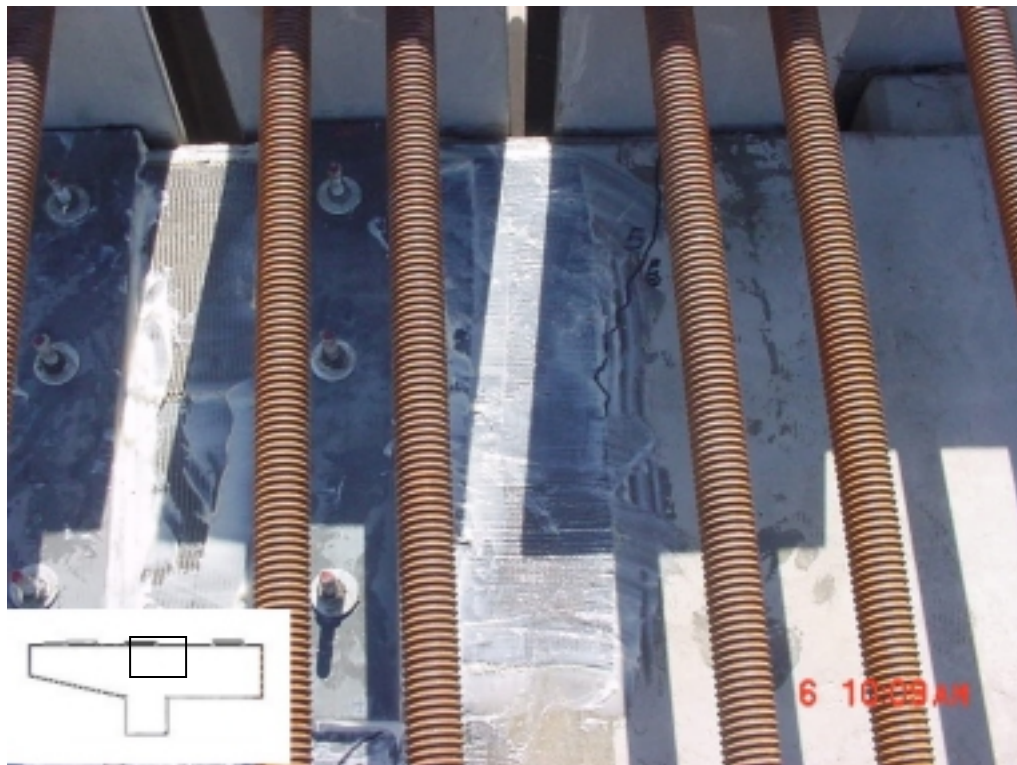


Figure 4.105 – Bent 13N, cracks at the end of FRP wraps after cycle 5





Figure 4.106 – Bent 13N, crack around FRP wrap and steel plates after cycle 5





Figure 4.107 – Bent 13N, cracks on the face of the bent after cycle 5



Figure 4.108 – Bent 13N, cracks on the top of bent after cycle 5

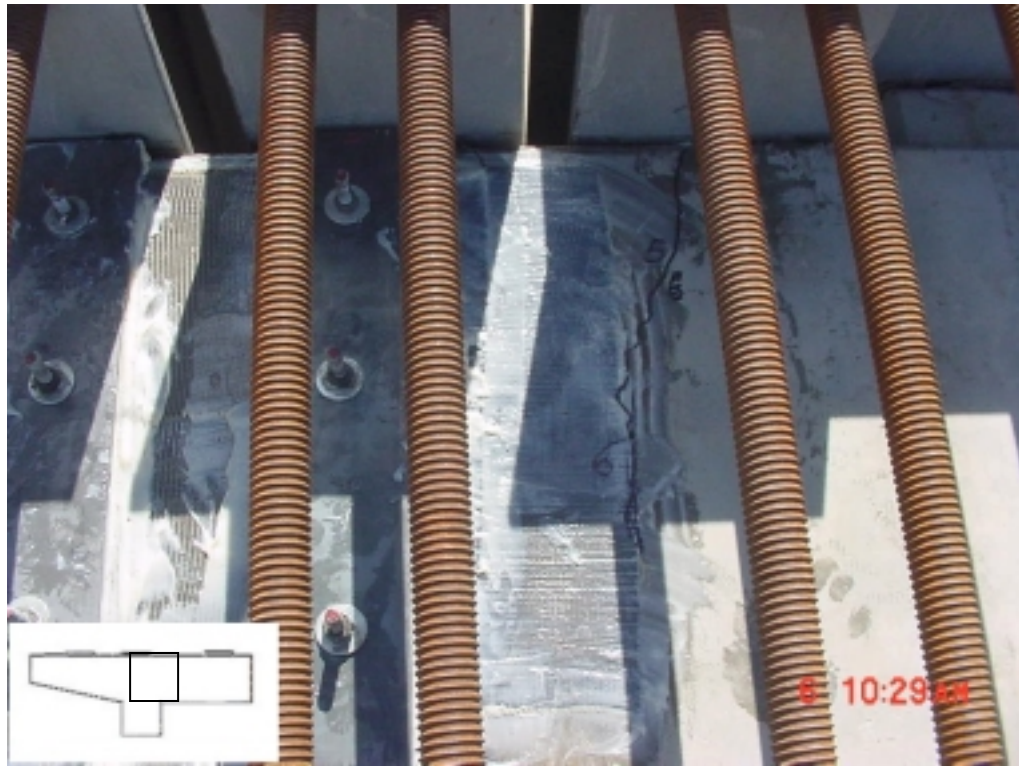


Figure 4.109 – Bent 13N, cracks at the end of FRP wraps after cycle 6

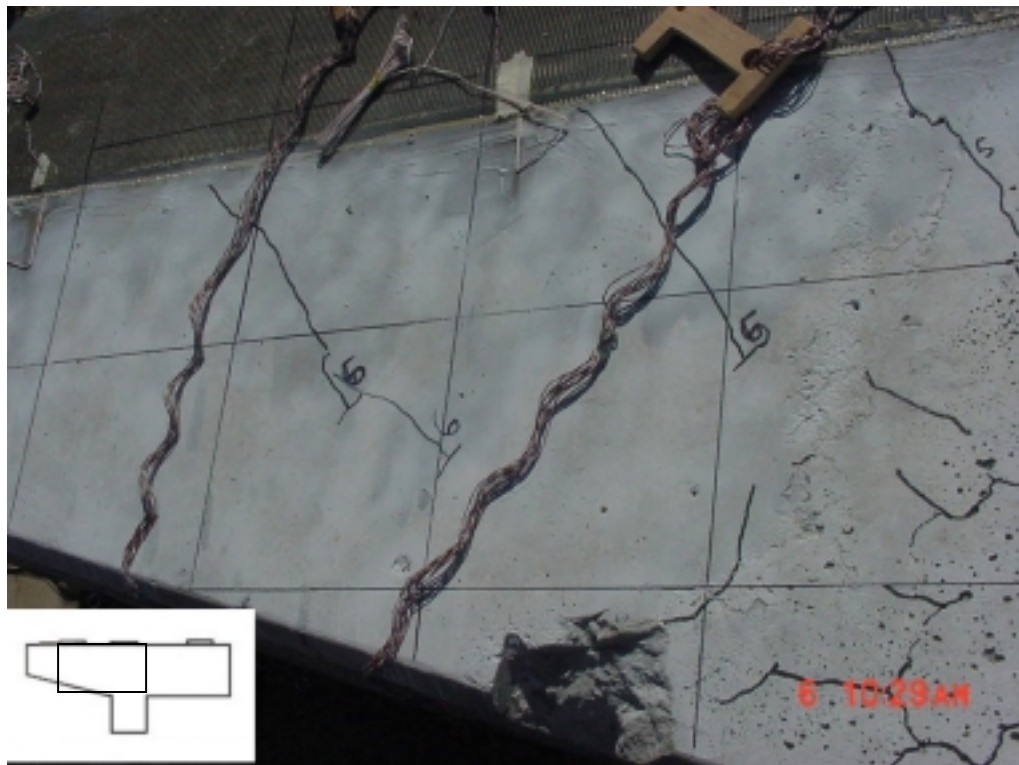


Figure 4.110 – Bent 13N, cracks on the face of the bent after cycle 6

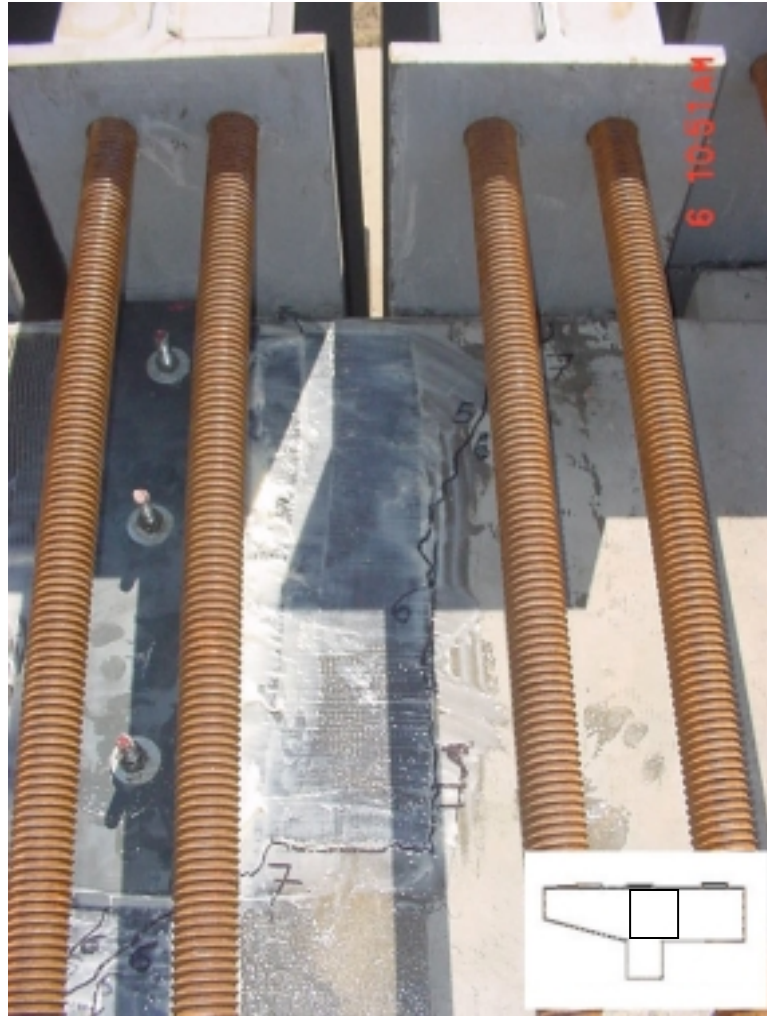


Figure 4.111 – Bent 13N, cracks at the end of FRP wraps after cycle 7





Figure 4.112 – Bent 13N, cracks on the face of the bent after cycle 7



Figure 4.113 – Bent 13N, cracks on the top of bent after cycle 7



Figure 4.114 – Bent 13N, cracks on the top of bent after cycle 8

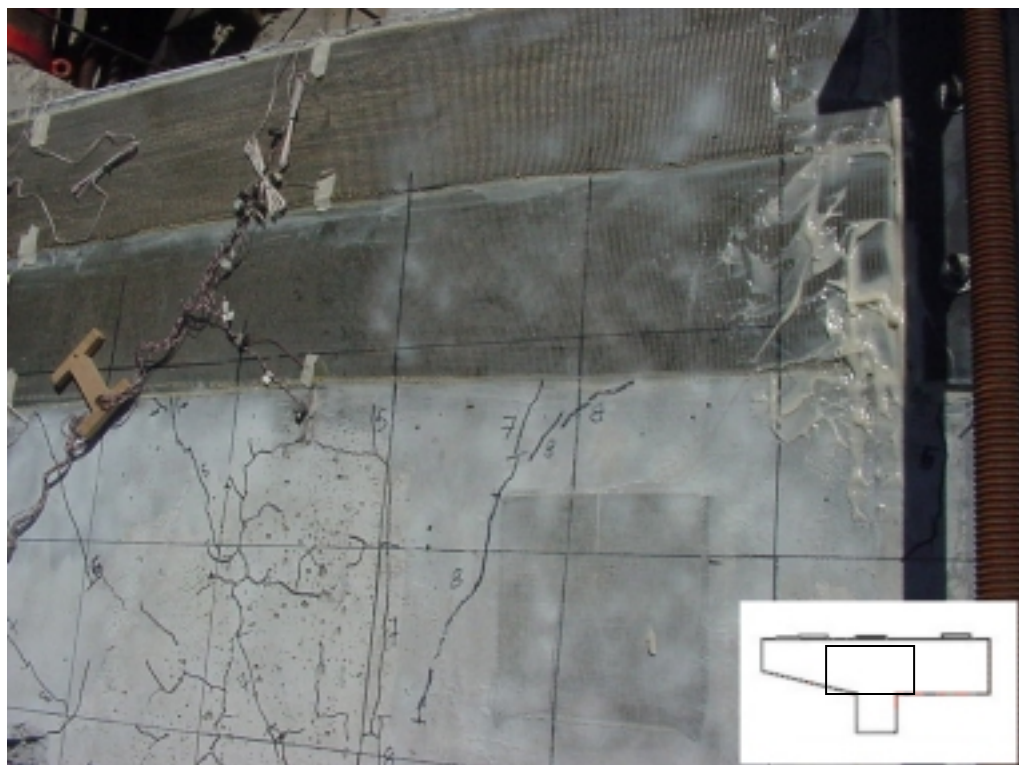


Figure 4.115 – Bent 13N, cracks on the face of the bent after cycle 8





Figure 4.116 – Bent 13N, cracks on the top of bent after cycle 9

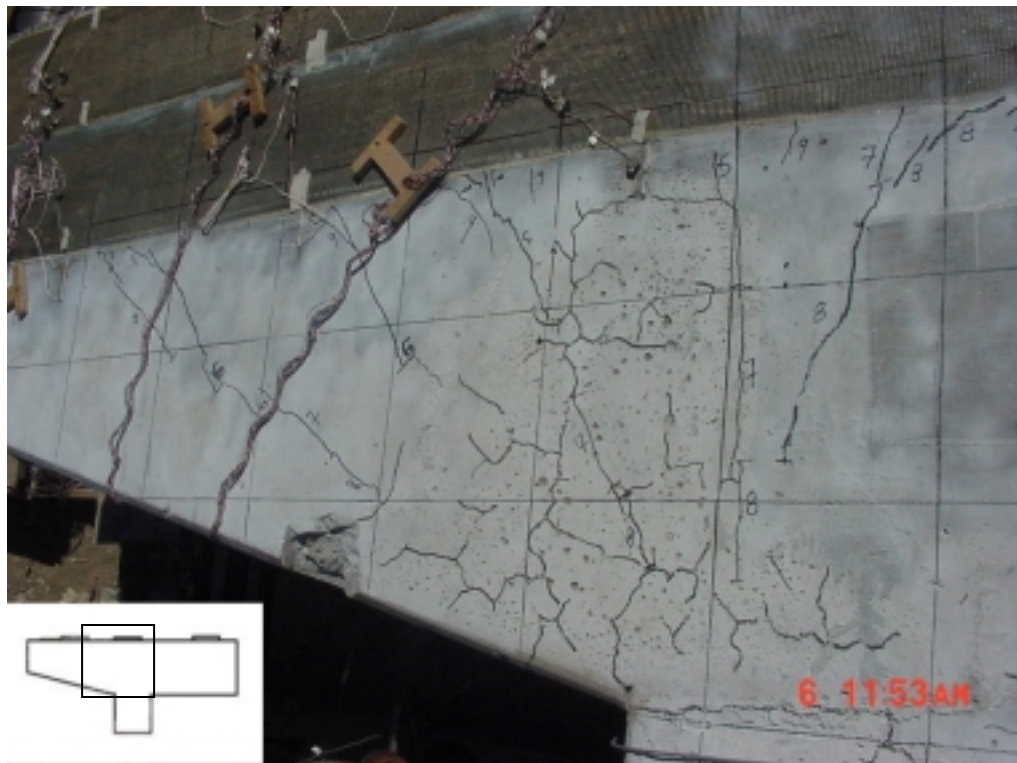


Figure 4.117 – Bent 13N, cracks on the face of the bent after cycle 9

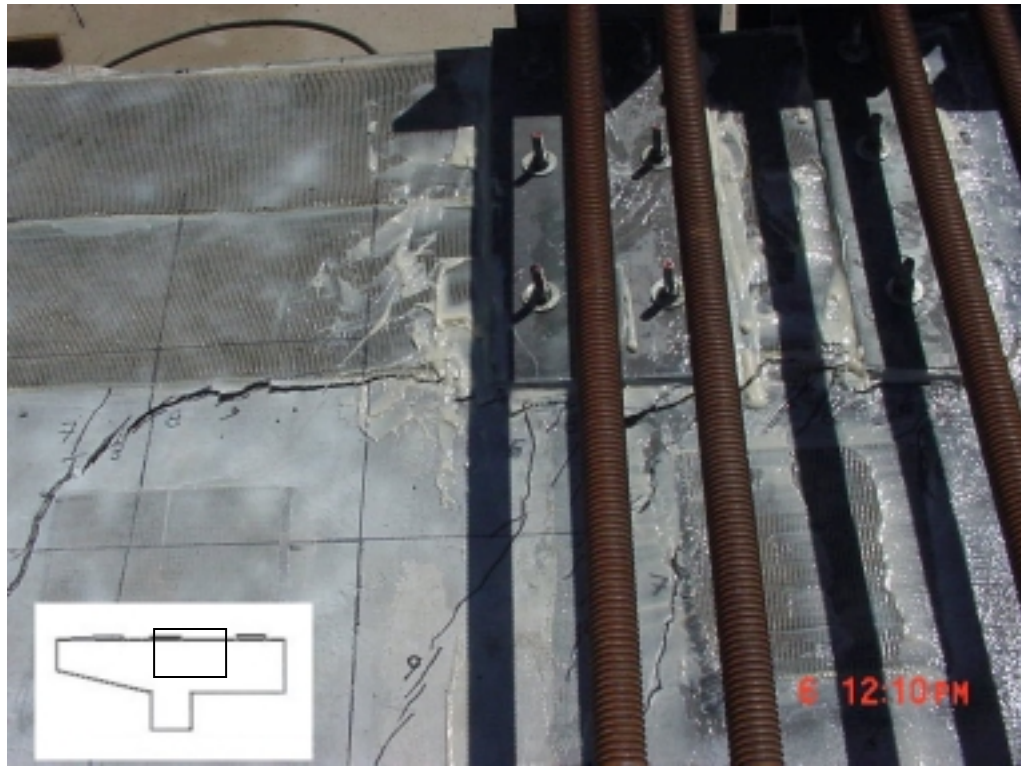


Figure 4.118 – Bent 13N, crack around FRP wrap and steel plates after cycle 9



Figure 4.119 – Bent 13N, gap caused by the crack around FRP wrap and steel plates after cycle 9





Figure 4.120 – Bent 13N, gap at the end of FRP wrap after cycle 9



Figure 4.121 – Bent 13N, buckling of FRP wrap during cycle 10



Figure 4.122 – Bent 13N, crack around FRP wrap and steel plates during cycle 10



Figure 4.123 – Bent 13N, cracks on the top of bent after cycle 10





Figure 4.124 – Bent 13N, crack approximately 0.375 in (13 mm) wide after cycle 10



Figure 4.125 – Bent 13N, condition of the bent after testing



Figure 4.126 – Bent 13N, sheared bolts of the anchorage system

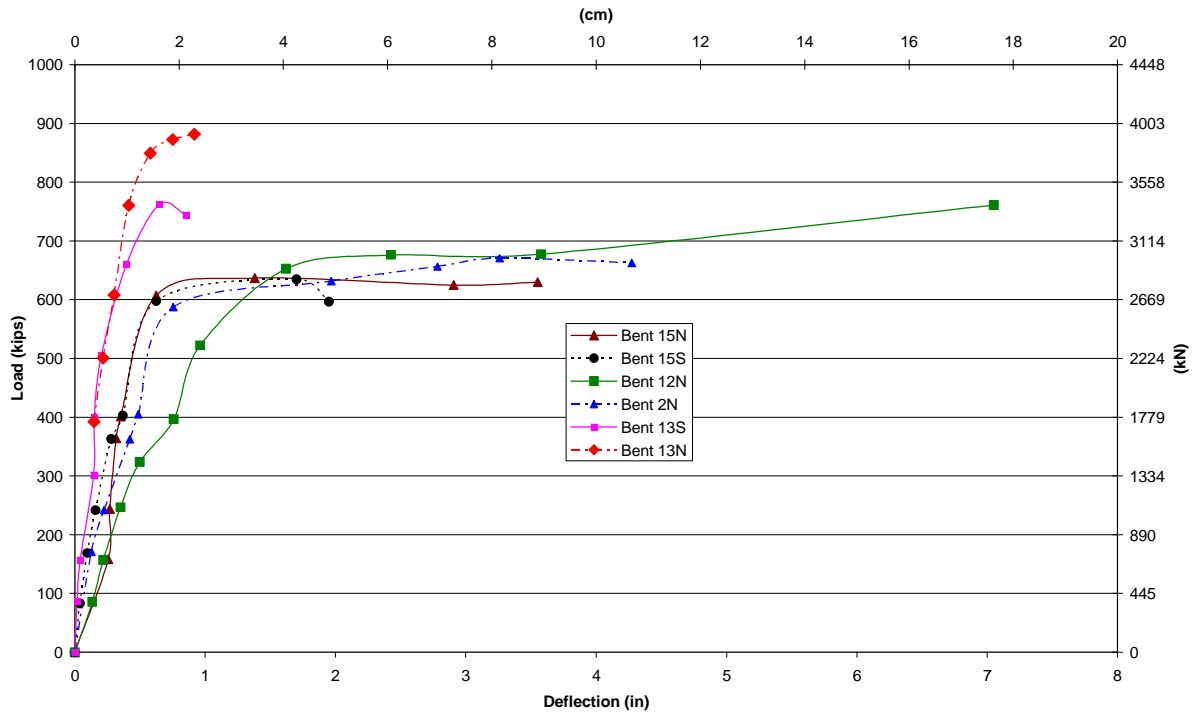


Figure 5.1 – Comparative Load vs. Deflection graph for all bents tested.

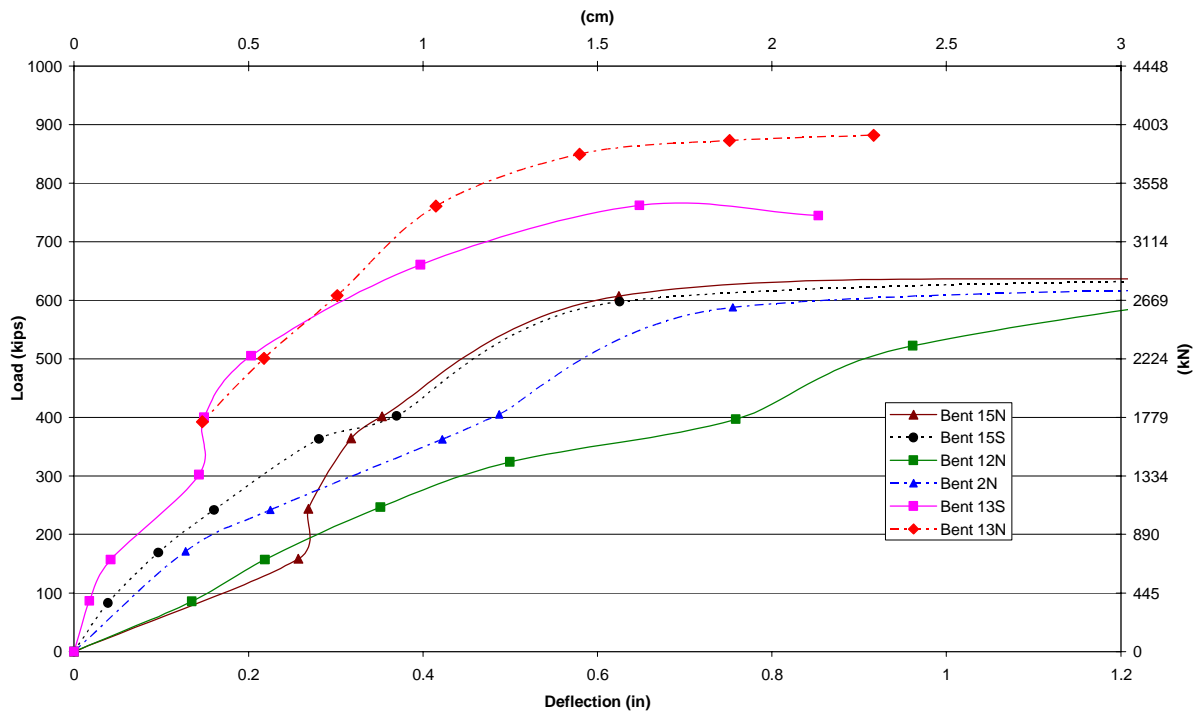


Figure 5.2 – Comparative Load vs. Deflection graph (up to yield load shown) for all bents tested.

**Appendix A:**  
**Repair Material Specifications**



## **SECTION 03922**

# **DELAMINATION REPAIR**

### **PART 1 GENERAL**

#### **1.1 SECTION INCLUDES**

- A. Repair delaminated concrete areas.

#### **1.2 PAYMENT PROCEDURES**

- A. This item is included in other items of work.

#### **1.3 RELATED SECTIONS**

- A. Section 03055: Portland Cement Concrete.
- B. Section 03310: Structural Concrete.

#### **1.4 REFERENCES**

- A. AASHTO M 235: Epoxy Resin Adhesives.

#### **1.5 ACCEPTANCE**

- A. Rebuild the areas to original shape,  $\pm 1/8$  inch.
- B. Remove and repair if the patching fails to bond. Department does not allow additional compensation for continual repair.

## **PART 2      PRODUCTS**

### **2.1      MATERIALS**

- A.    Repair Concrete:
  - 1.    Portland Cement Concrete: Class AA(AE). Refer to Section 03055, Part 2.
  - 2.    Cement: Type II. Refer to Section 03055, Part 2.
  - 3.    Aggregate: 3/4 inch maximum.
- B.    Patching Concrete:
  - 1.    Select from the Performance Data Products Listing (PDPL) maintained by the UDOT Research Division.
  - 2.    Only use products for which the manufacturer recommends vertical application.
- C.    Substrate Coating: Use a bonding agent or primer recommended by the particular patching concrete manufacturer.
- D.    Epoxy Resin Adhesive: Type II. AASHTO M 235.
  - 1.    Use a class rating consistent with the application temperature.
  - 2.    Select from the Performance Data Products Listing (PDPL) maintained by the UDOT Research Division.
- E.    Surface Sealing Material (Penetrating Type): Select from the Accepted Products Listing (APL) maintained by the UDOT Research Division.

### **2.2      MIXER**

- A.    Use an approved type of small mixer to batch out the repair concrete when specifically approved by the Engineer.

## **PART 3      EXECUTION**

### **3.1      PREPARATION**

- A.    Locate the repair areas: Sound the items requiring this work and mark the limits of delaminated areas for repair work in the presence of the Engineer.
- B.    Remove concrete:
  - 1.    Remove all loose materials by dry sweeping.

2. Clean by blowing with compressed air at 90 psi.
  3. Make ½ inch deep saw cuts in the sound concrete surrounding the damaged areas.
  4. Remove all damaged and shattered concrete.
- C. Cleaning:
1. Remove all loose materials by dry sweeping.
  2. Clean by blowing with compressed air at 90 psi.
  3. Sandblast clean all exposed reinforcing steel and concrete surfaces before placing new concrete.

## **3.2 INSTALLATION**

- A. Form Work
1. Use forms and braces to place new concrete to the original dimensions.
  2. Vibration is required in the forms when the area between forms and existing concrete surface will allow use of vibrators.
- B. Use one type of repair concrete.
- C. Placing concrete when thickness to be placed is less than or equal to 3 inches:
1. Use patching concrete.
  2. Coat the cleaned concrete using the manufacturer's recommended primer.
  3. Place patching concrete in layers not exceeding the manufacturer's recommended application thickness per layer.
  4. Apply the surface sealer recommended by the manufacturer.
  5. Consult the manufacturer's recommendations for finishing.
- D. Placing concrete when thickness to be placed is greater than 3 inches:
1. Apply an epoxy-resin adhesive to the cleaned concrete surface of the repair area before placing the new concrete.
  2. Place the concrete and allow to cure following the requirements of Section 03310, articles, "Concrete Surface Finishing Classifications," "Concrete Surface Finishing," and "Concrete Surface Finishing Procedures."
  3. After the concrete has properly cured, sandblast the finished concrete surfaces and coat with a non-penetrating type epoxy sealer. Follow the manufacturer's procedure.
- E. Finished surfaces: Provide the look of one color.

END OF SECTION

**Change One - August 29, 2002**  
**No changes made**

**Change Two - December 19, 2002**  
**No changes made**

**Change Three - February 27, 2003**  
**No changes made**

**Change Four - April 24, 2003**  
**Revised Articles**

**2.1 B 1**

**2.1 B 2**

**2.1 D 2**

**2.1 E**



## **SECTION 03924**

# **STRUCTURAL CONCRETE REPAIR**

## **PART 1 GENERAL**

### **1.1 SECTION INCLUDES**

- A. Restore to sound condition:
  - 1. Column
  - 2. Pedestal
  - 3. Bent Cap
  - 4. Pier Cap
  - 5. Diaphragm
  - 6. Wingwall
  - 7. Abutment Backwall
  - 8. Beam End

### **1.2 RELATED SECTIONS**

- A. Section 03922: Delamination Repair
- B. Section 03935: Epoxy Injection and Sealing

## **PART 2 PRODUCTS**

### **2.1 MATERIALS**

- A. Refer to Sections 03922 and 03935.

### **2.2 BEAM END REPAIR SURFACE SEALING MATERIAL**

- A. Penetrating type.
- B. Select from the Accepted Products Listing (APL) maintained by the UDOT Research Division.

## **PART 3      EXECUTION**

### **3.1      CRACK REPAIR**

- A.      Repair cracks from 1/64 inch to 1/4 inch wide by epoxy injection and sealing. See Section 03935.
- B.      Repair cracks greater than 1/4 inch wide as “delaminated concrete.”

### **3.2      DELAMINATION REPAIR**

- A.      Repair delaminated concrete by delamination repair. Refer to Section 03922.
- B.      Beam End Delamination Repair: Use a patching concrete.
- C.      After concrete removal:
  - 1.      Repair any crack found in a delaminated area according to Section 03935.
  - 2.      After the injection operation, apply surface sealing after repairing the delaminated area.
- D.      When surface sealing after crack injection and delamination repair operations:
  - 1.      Use epoxy sealer for surface sealing exclusively.
  - 2.      Apply sealer to a minimum beam length of 4 ft covering all surfaces in that beam segment.

END OF SECTION

**Change One - August 29, 2002**

**No changes made**

**Change Two - December 19, 2002**

**No changes made**

**Change Three - February 27, 2003**

**No changes made**

**Change Four - April 24, 2003**

**Revised Article**

**2.2 A, B**

## **SECTION 03935**

# **EPOXY INJECTION AND SEALING**

## **PART 1 GENERAL**

### **1.1 SECTION INCLUDES**

- A. Repair concrete cracks by injecting epoxy and sealing the concrete surfaces.

### **1.2 PAYMENT PROCEDURES**

- A. These items are included in other items of work.

### **1.3 ACCEPTANCE**

- A. Penetration of 95 percent of all cracks from 1/64 inch to 1/4 inch wide is required.

### **1.4 DELIVERY**

- A. Deliver the packages materials in unopened packages with labels clearly indicating the following:
  - 1. Name of Manufacturer
  - 2. Manufacturer's product name or product number
  - 3. Manufacturer's lot number
  - 4. Mix ratio
  - 5. SPI Hazardous Material Rating and appropriate warnings for handling

## **PART 2 PRODUCTS**

### **2.1 MATERIALS**

- A. Select from the Performance Data Products Listing (PDPL) maintained by the UDOT Research Division.

1. Epoxy Injection Material:
  - a. Use only products for which vertical crack injection is recommended by the manufacturer.
  - b. Use appropriate cap seal material recommended by the particular epoxy manufacturer.
2. Surface Sealing Material: Penetrating sealer.

## **2.2 EQUIPMENT**

- A. Minimum of two pumps with the following required characteristics:
  1. Electric-powered and portable.
  2. Positive displacement.
  3. Positive-ratio control of exact proportions of the two components at the nozzle.
  4. In-line metering and mixing.
- B. Injection equipment required characteristics:
  1. Automatic pressure control capable of discharging the mixed adhesive at any pre-set pressure up to 200 psi " 0.5 psi.
  2. Equipped with a manual pressure control override.
- C. Capable of maintaining the volume ratio of the injection material prescribed by the manufacturer within a tolerance of " 5 percent by volume at any discharge pressure up to 200 psi.
- D. With sensors on both the component A and B reservoirs that automatically stop the machine when only one component is being pumped to the mixing head.

## **PART 3 EXECUTION**

### **3.1 INSTALLERS**

- A. Injection equipment operators must have a minimum of 2 years experience in the methods and materials of the selected system for application of epoxy injection.
- B. Injection equipment operators must know the technical aspects of:
  1. Correct material selection and use.
  2. Equipment operation, maintenance, and troubleshooting.



### **3.2 PREPARATION**

- A. Sandblast clean the concrete surfaces.
- B. Seal cracks.
- C. Provide entry ports for the epoxy injection. Space ports a maximum of 6 inches.

### **3.3 EPOXY INJECTION**

- A. Proceed from lower to higher ports.
- B. When epoxy appears at a higher port, plug the port being injected and move to a higher port.

### **3.4 EPOXY SEALING**

- A. Grind flush all ports extending above the concrete surfaces.
- B. Apply the sealant at the minimum application rate of 0.09 gal/yd<sup>2</sup>.
- C. Cover the entire length of the crack with epoxy sealant for a minimum of 2 ft on either side of the crack.
- D. Mask the member so a straight vertical line is produced at the cutoff point.
- E. Apply a second coat at the same application rate as soon as the first coat is dry to the touch. Do not exceed the following times between coats:

<b>Hours</b>	<b>Temperature (Degrees F)</b>
72	66
36	77
24	90

END OF SECTION

**Change One - August 29, 2002**  
**No changes made**

**Change Two - December 19, 2002**  
**No changes made**

**Change Three - February 27, 2003**  
**No changes made**

**Change Four - April 24, 2003**  
**Revised Article**

**2.1 A**

**2.1 A 2**



# Sika Armatec® 110 EpoCem®

**Bonding Agent and Reinforcement Protection**

3/02

## DESCRIPTION

Sika Armatec 110 EpoCem is a 3-component, solvent-free, moisture-tolerant, epoxy-modified, cementitious product specifically formulated as a bonding agent and an anti-corrosion coating.

## WHERE TO USE

- ▲ As an anti-corrosion coating for reinforcing steel in concrete restoration.
- ▲ As added protection to reinforcing steel in areas of thin concrete cover.
- ▲ As a bonding agent for repairs to concrete and steel.
- ▲ As a bonding agent for placing fresh, plastic concrete to existing hardened concrete.

## ADVANTAGES

- ▲ Excellent adhesion to concrete and steel.
- ▲ Acts as an effective barrier against penetration of water and chlorides.
- ▲ Long open time - up to 24 hours.
- ▲ Not a vapor barrier.
- ▲ Can be used exterior on-grade.
- ▲ Contains corrosion inhibitors.
- ▲ Excellent bonding bridge for cement or epoxy based repair mortars.
- ▲ High strength, unaffected by moisture when cured.
- ▲ Spray, brush or roller application.
- ▲ Non-flammable, solvent free.

## COVERAGE

**Bonding agent:** minimum (theoretical) on smooth, even substrate 80 sq.ft./gal. (=20 mils thickness). Coverage will vary depending on substrate profile and porosity.

**Reinforcement Protection:** 40 sq. ft./gal. (=20 mils thickness) (2 coat application).

## PACKAGING

3.5 gal. unit. (47.6 fl. oz. Comp. A + 122.1 fl. oz. Comp. B + 46.82 lb. Comp. C) Comp. A+B in carton, Comp. C in multi-wall bag.  
1.65 gal. unit. (22.7 fl. oz. A + 57.6 fl. oz. B + 4 bags @ 5.5 lb.) Factory-proportioned units in a pail.

## HOW TO USE

### SURFACE PREPARATION

**Cementitious substrates:** Should be cleaned and prepared to achieve a laitance and contaminant-free surface prepared in accordance with the requirements specified by the overlay or repair material by blastcleaning or equivalent mechanical means. Substrate must be saturated surface dry (SSD) with no standing water.

**Steel:** Should be cleaned and prepared thoroughly by blastcleaning.

### TYPICAL DATA FOR SIKA ARMATEC 110 (Material and curing conditions @ 73F and 50% R.H.)

<b>SHELF LIFE</b>	1 year in original, unopened packaging.
<b>STORAGE CONDITIONS</b>	Store dry at 40-95F (4-35 C). <b>Condition material to 65-75F (18-24C) before using.</b> If components A and B are frozen, discard. Protect Component C from humidity.

<b>COLOR</b>	Concrete gray
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<b>DENSITY (MIXED)</b>	125 lb./cu.ft. (2.0 kg)
------------------------	-------------------------

<b>POT LIFE</b>	Approximately 90 minutes
-----------------	--------------------------

<b>COMPRESSIVE STRENGTH</b> (ASTM C-109)	3 days	4500 psi	(31.0 MPa)
	7 days	6500 psi	(44.8 MPa)
	28 days	8500 psi	(58.6 MPa)

<b>FLEXURAL STRENGTH</b> (ASTM C-348)	28 days	1250 psi	(8.6 MPa)
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<b>SPLITTING TENSILE STRENGTH</b> (ASTM C-496)	28 days	600 psi	(4.1 MPa)
---------------------------------------------------	---------	---------	-----------

### IMPORTANT DATA FOR SIKA ARMATEC 110 AS A CORROSION PROTECTIVE COATING

<b>WATER</b>			
Water Permeability at 10 bar (145 psi)	8.92 x 10 <sup>-15</sup>	ft./sec.	
Control	7.32 x 10 <sup>-10</sup>	ft./sec.	
Water vapor diffusion coefficient $\mu$ H <sub>2</sub> O	110		

<b>CARBON DIOXIDE</b>	
Carbon dioxide diffusion coefficient $\mu$ CO <sub>2</sub>	14000

### TEST DATA: Time-to-Corrosion Study

- ▲ Sika Armatec 110 more than tripled the time to corrosion
- ▲ Reduced corrosion rate by over 40%

### IMPORTANT DATA FOR SIKA ARMATEC 110 AS A BONDING AGENT

#### BOND STRENGTH (ASTM C882)

<b>14 days moist cure, plastic concrete to hardened concrete:</b>			
Wet on Wet	2800 psi	(19.3 MPa)	
24hr. open time	2600 psi	(17.9 MPa)	

<b>Bond of Steel Reinforcement to Concrete (Pullout Test):</b>			
Sika Armatec 110 coated	625 psi	(4.3 MPa)	
Epoxy coated	508 psi	(3.5 MPa)	
Plain Reinforcement	573 psi	(3.95 MPa)	

### MIXING

Shake contents of both Component 'A' and Component 'B'. Empty entire contents of both Component 'A' and Component 'B' into a clean, dry mixing pail. Mix thoroughly for 30 seconds with a Sika paddle on a low speed (400-600 rpm) drill. Slowly add the entire contents of Component 'C' while continuing to mix for 3 minutes until blend is uniform and free of lumps. Mix only that quantity that can be applied within its pot life.

### APPLICATION

**As a bonding agent** - Apply by stiff-bristle brush or broom. Spray apply with Goldblatt Pattern Pistol or equal equipment. For best results, work the bonding slurry well into the substrate to ensure complete coverage of all surface irregularities. Apply the freshly mixed patching mortar or concrete wet on wet, or up to the maximum recommended open time, onto the bonding slurry.

**Maximum recommended open time between application of Armatec 110 and patching mortar or concrete:**

<b>95F (35 C)</b>	<b>6 hours</b>
<b>68F (20 C)</b>	<b>12 hours</b>
<b>50F (10 C)</b>	<b>16 hours</b>
<b>40F ( 5 C)</b>	<b>24 hours</b>

Extended open times are possible. For details, please contact Technical Service. **For corrosion protection** - Apply by stiff-bristle brush or spray at 80 sq. ft./gal. (20 mils). Take special care to properly coat the underside of the totally exposed steel. Allow coating to dry 2-3 hours @ 73F, then apply a second coat at the same coverage. Allow to dry again before the repair mortar or concrete is applied. Pour or place repair within 7 days.

**LIMITATIONS**

- ▲ Substrate and ambient temperature:  
Minimum 40F (5C)  
Maximum 95F (35C)
- ▲ Minimum thickness: As a bonding agent 20 mils.
- ▲ For reinforcement protection 40 mils (2 coats, 20 mils each).
- ▲ Not recommended for use with expansive grouts.
- ▲ Use of semi-dry mortars onto Sika Armatec 110 EpoCem must be applied "wet on wet".
- ▲ When used in overhead applications with hand placed patching mortars, use "wet on wet" for maximum mortar build thickness.
- ▲ Substrate profile as specified by the overlay or repair material is still required.

- ▲ As with all cement based materials, avoid contact with aluminum to prevent adverse chemical reaction and possible product failure. Insulate potential areas of contact by coating aluminum bars, rails, posts etc. with an appropriate epoxy such as Sikadur Hi-Mod 32.

**CAUTION**

**PART A & B:**

**IRRITANT; SENSITIZER** - Can cause skin sensitization after prolonged or repeated contact. Skin and eye irritant. High concentrations of vapor may cause respiratory irritation. Avoid skin contact. Use only with adequate ventilation. Use of safety goggles and chemical resistant gloves is recommended.

**PART C:**

**IRRITANT; SUSPECT CARCINOGEN** - Contains crystalline silica, quartz (sand); cement. Skin and eye irritant. Dust may cause respiratory tract irritation. Avoid breathing dust. Use only with adequate ventilation. May cause delayed lung injury (silicosis). IARC list crystalline silica as having sufficient evidence of carcinogenicity to laboratory animals and limited evidence of carcinogenicity in humans. NTP also lists crystalline silica as a suspect carcinogen. Use of safety gloves is recommended. In case of high dust concentrations or exceedance of PELs, use an appropriate NIOSH/MSHA approved respirator.

**FIRST AID**

In case of eye contact, wash immediately with soap and water for 15 minutes; immediately consult a physician. In case of skin contact, wash with soap and water; consult a physician for irritation. For respiratory problems, remove person to fresh air and institute artificial respiration if necessary; consult a physician. In case of ingestion, immediately consult a physician. Wash clothing before reuse.

**CLEAN-UP**

In case of spills or leaks, wear suitable protective equipment, contain spill, collect with absorbent material, and transfer to a suitable container. Ventilate area. Avoid contact. Dispose of in accordance with current, applicable local, state, and federal regulations.

Product Code 182. Sika and Armatec are registered trademarks. Made in USA. Printed in USA. March, 2002.

**KEEP CONTAINER TIGHTLY CLOSED  
NOT FOR INTERNAL CONSUMPTION**

**KEEP OUT OF REACH OF CHILDREN  
FOR INDUSTRIAL USE ONLY**

**CONSULT MATERIAL SAFETY DATA SHEET FOR MORE INFORMATION**

Sika warrants its products to be free from manufacturing defects and to meet Sika's current published properties when applied in accordance with Sika directions and tested in accordance with ASTM and Sika Standards. User determines suitability of product for use and assumes all risks. Buyer's sole remedy shall be limited to the purchase price or replacement of product and excludes labor or the cost of labor. Any claim for breach of this warranty must be brought within one year of the date of purchase.

**NO OTHER WARRANTIES EXPRESSED OR IMPLIED INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE SHALL APPLY. SIKA SHALL NOT BE LIABLE FOR ANY CONSEQUENTIAL OR SPECIAL DAMAGES OF ANY KIND, RESULTING FROM ANY CLAIM OF BREACH OF WARRANTY, BREACH OF CONTRACT, NEGLIGENCE OR ANY LEGAL THEORY. SIKA ASSUMES NO LIABILITY FOR USE OF THIS PRODUCT IN A MANNER TO INFRINGE ON ANOTHER'S PATENT.**

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**Sika Mexicana S.A. de C.V.**  
Carretera Libre Celaya Km. 8.5  
Corregidora, Queretaro  
C.P. 76920 A.P. 136  
Phone: 52 42 25 0122  
Fax: 52 42 25 0537

Quality Certification Numbers: Lyndhurst: 93-062B, Marion: 93-086B, Kansas City: 94-258B, Santa Fe Springs: 94-195C



Spec Component: SC-200-1292  
Supersedes: SC-200-0191

### Part 3 - Scope: Product and Application

This specification describes the bonding bridge between new portland cement mortar/concrete and hardened portland cement mortar/concrete and the corrosion protection of reinforcing steel with an epoxy resin/portland cement adhesive.

#### 3.01 Acceptable Manufacturers

- A. Sika Armatex 110, as manufactured by Sika Corporation, Lyndhurst, New Jersey, is considered to conform to the requirements of this specification and has performed satisfactorily for bonding plastic portland cement mortar/concrete to hardened portland cement mortar/concrete.
- B. Substitutions: The use of other than the specified product will be considered providing the contractor requests its use in writing to the Engineer. This request shall be accompanied by (a) A certificate of compliance from an approved independent testing laboratory that the proposed substitute product meets or exceeds the specified performance criteria, tested in accordance with the specified test standards; and (b) Documented proof that the proposed substitute product has a one year proven record of performance of bonding plastic portland cement mortar/concrete to hardened portland cement mortar/concrete, confirmed by actual field tests and five successful installations that the Engineer can investigate.

#### 3.02 Performance Criteria

- A. Properties of the mixed epoxy resin/portland cement adhesive.
  - 1. Pot Life: 75-105 minutes
  - 2. Contact Time: 24 hours
  - 3. Color: dark gray
- B. Properties of the cured epoxy resin/portland cement adhesive.
  - 1. Compressive Strength (ASTM C-109)
    - a. 1 day: 810 psi min.
    - b. 7 day: 6,000 psi min.
    - c. 28 day: 8,000 psi min.
  - 2. Splitting Tensile Strength (ASTM C-496)
    - a. 28 days: 540 psi min.
  - 3. Flexural Strength (ASTM C-348)
    - a. 1100 psi min.
  - 4. Bond Strength (ASTM C-882 modified) at 14 days
    - a. 0 hrs. open time: 1,900 psi min.
    - b. 24 hrs. open time: 1,500 psi min.
  - 5. The epoxy resin/portland cement adhesive shall not produce a vapor barrier.
  - 6. Material must be proven to prevent corrosion of reinforcing steel when tested under the procedures as set forth by the Federal Highway Administration Program Report No. FHWA/RD86/193. Proof shall be in the form of an independent testing laboratory corrosion report showing prevention of corrosion of the reinforcing steel.

#### 3.03 Materials

- A. Epoxy resin/portland cement adhesive:
  - 1. Component "A" shall be an epoxy resin/water emulsion containing suitable viscosity control agents. It shall not contain butyl glycidyl ether.
  - 2. Component "B" shall be primarily a water solution of a polyamine.



3. Component "C" shall be a blend of selected portland cements and sands.
4. The material shall not contain asbestos.

#### **3.04 Mixing and Application**

- A. Mixing the epoxy resin: Shake contents of Components "A" and Component "B". Empty all of both components into a clean, dry mixing pail. Mix thoroughly for 30 seconds with a jiffy paddle on a low-speed (400-600 rpm) drill. Slowly add the entire contents of Component "C" while continuing to mix for 3 minutes until uniform with no lumps. Mix only that quantity that can be applied within its pot life.
- B. Placement procedure:
  1. Apply to approved prepared surface with a stiff-bristle brush, broom or "hopper type" spray equipment.
    - a. For hand applications - Place fresh, plastic concrete/mortar while the bonding bridge adhesive is wet or dry, up to 24 hours.
    - b. For machine applications - Allow the bonding bridge adhesive to dry for 12 hours minimum.

Note: For polymer-modified mortars/concretes, it is necessary, when the adhesive has dried, to pre-saturate the substrate and scrub coat the repair material into the surface.

- C. Adhere to all limitations and cautions for the epoxy resin/portland cement adhesive in the manufacturers current printed literature.

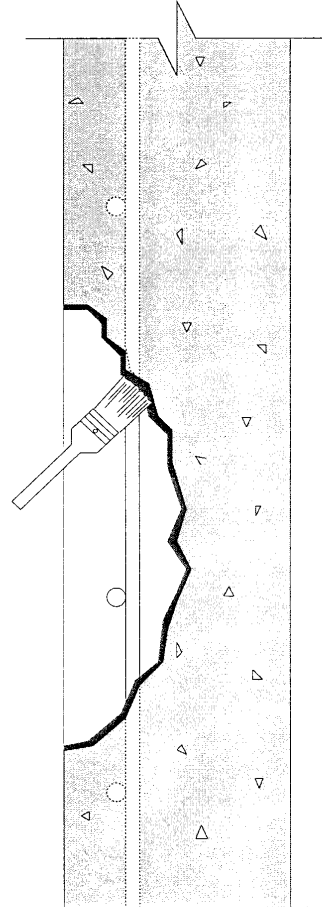
#### **3.05 Cleaning**

- A. The uncured epoxy resin/portland cement adhesive can be cleaned from tools with water. The cured epoxy resin/portland cement adhesive can only be removed mechanically.
- B. Leave finished work and work area in a neat, clean condition without evidence of spillovers onto adjacent areas.

Note: Tests above were performed with material and curing conditions at 71-75F and 45-55% relative humidity.

# SC-200      Sika® Armatec 110 Bonding Bridge

1. Pre-wet surface to saturated surface dry (SSD).
2. Apply by stiff bristle brush or spray apply with "Goldblatt pattern pistol" or equal equipment.
3. Place repair material while Sika Armatec 110 is still wet or dry up to 24 hours.



Client Name:	_____
Job Name:	_____
Date:	_____



# Sika MonoTop® 615

3/00

**One-component, polymer-modified, silica fume enhanced, lightweight, non-sag mortar**

## DESCRIPTION

Sika MonoTop 615 is a one-component, polymer-modified, silica fume enhanced, cementitious, non-sag mortar. It is a multi-purpose mortar which can be applied by trowel or low pressure wet spray process.

## WHERE TO USE

- ▲ On buildings, facades, and balconies.
- ▲ On grade, above, and below grade on concrete and mortar.
- ▲ On vertical, overhead, and horizontal surfaces.
- ▲ As a general purpose repair mortar for use on concrete structures in a mild or moderate service environment.

## ADVANTAGES

- ▲ One component, factory controlled for consistent quality.
- ▲ To be mixed with potable water only.
- ▲ Excellent workability.
- ▲ Adjustable consistency.
- ▲ Excellent thixotropic behavior, especially suitable for overhead and vertical application.
- ▲ Good mechanical strengths.
- ▲ High bond strength ensures excellent adhesion.
- ▲ Increased freeze/thaw durability and resistance to deicing salts.
- ▲ Compatible modulus of elasticity to concrete generally used for building/facade construction.
- ▲ Compatible with coefficient of thermal expansion of concrete - Passes ASTM C-884 (modified).
- ▲ Application by hand or low pressure wet spray method.
- ▲ Not a vapor barrier.
- ▲ Not flammable, non-toxic.

## YIELD

0.55 cu. ft./bag.

## PACKAGING

50 lb. multi-wall bag.

## HOW TO USE

### SUBSTRATE

Concrete, mortar, and masonry products.

### SURFACE PREPARATION

**Concrete / Mortar:** Remove all deteriorated concrete, dirt, oil, grease, and all bond-inhibiting materials from surface. Be sure repair area is not less than 1/8 in. in depth. Preparation work should be done by high pressure water blast (over 20,000 psi), scabblers, or other appropriate mechanical means to obtain an exposed aggregate surface with a minimum surface

## TYPICAL DATA FOR SIKA MONOTOP 615 (Material and curing conditions @ 73°F (23°C) and 50% R.H.)

<b>SHELF LIFE:</b>	One year in original, unopened packaging.	
<b>STORAGE CONDITIONS:</b>	Store dry at 40-95°F (4-35°C). <b>Condition material to 65-75°F before using.</b>	
<b>COLOR:</b>	Concrete gray when mixed.	
<b>MIXING RATIO:</b>	3.5 qts. (±0.25 qts.) of water per 50 lb. bag as required for desired consistency, (water:powder ratio = 0.146:1).	
<b>APPLICATION TIME:</b>	Approximately 45 min. after adding water. Application time is dependent on temperature and humidity.	
<b>FINISHING TIME:</b>	Approximately 60 min. after adding water: depends on temperature, relative humidity, and type of finish desired.	
<b>DENSITY (WET MIX):</b>	104 lbs./cu.ft.	(1.65 kg./l)
<b>FLEXURAL STRENGTH (ASTM C-293):</b>		
	<b>28 days</b>	1,000 psi (6.9 MPa)
<b>SPLITTING TENSILE STRENGTH (ASTM C-496):</b>		
	<b>28 days</b>	400 psi (2.8 MPa)
<b>BOND STRENGTH* (ASTM C-882 MODIFIED):</b>		
	<b>28 days</b>	1,000 psi (6.9 MPa)
<b>COMPRESSIVE STRENGTH (ASTM C-109):</b>		
	<b>1 day</b>	1,500 psi (10.3 MPa)
	<b>7 days</b>	3,500 psi (24.1 MPa)
	<b>28 days</b>	4,300 psi (29.7 MPa)
<b>CARBON DIOXIDE DIFFUSION COEFFICIENT (μ CO<sub>2</sub>)</b>	1,300	
<b>WATER VAPOR DIFFUSION COEFFICIENT (μ H<sub>2</sub>O)</b>	300	

\*Mortar scrubbed into substrate.

profile of ± 1/16 in. (CSP-5). Saturate surface with clean water. Substrate should be saturated surface dry (SSD) with no standing water during application.

**Reinforcing Steel:** Steel reinforcement should be thoroughly prepared by mechanical cleaning to remove all traces of rust. Where corrosion has occurred due to the presence of chlorides, the steel should be high-pressure washed with clean water after mechanical cleaning. For priming of reinforcing steel use Sika Top Armatec 110 EpoCem (consult Technical Data Sheet).

### PRIMING

#### Concrete Substrate:

Prime the prepared substrate with a brush or sprayed applied coat of Sika Armatec 110 EpoCem (consult Technical Data

Sheet). Alternately, a scrub coat of Sika MonoTop 615 can be applied prior to placement of the mortar. The repair mortar has to be applied into the wet scrub coat before it dries.

### MIXING

Pour water in the proper proportion (3.5 qts. ±0.25 qts. per bag) into the mixing container. Add powder while mixing continuously. Mix mechanically with a low-speed drill (400-600 rpm) and mixing paddle or mortar mixer. Mix to uniform consistency, minimum 3 minutes. Manual mixing can be tolerated only for less than a full bag.

#### APPLICATION & FINISH

Sika MonoTop 615 can be applied either by hand or wet spray process equipment. Mortar must be scrubbed into the substrate, filling all pores and voids; or the use of a bonding agent (Sika Armatex® 110) is recommended. Force Sika MonoTop 615 against edge of repair, working toward the center.

After filling repair, consolidate, then screed. Material may be applied in multiple lifts. The thickness of each lift, not to be less than 1/8 in. minimum or more than 2 in. maximum, may vary depending on the conditions of the repair area.

Where multiple lifts are required, score top surface of each lift to produce a roughened surface for next lift. Allow preceding lift to set before applying fresh material. Saturate surface of the lift with clean water. Scrub fresh mortar into preceding lift. Allow mortar to set to desired stiffness, then finish with wood or sponge float for a smooth surface, or texture as required.

#### CURING:

As per ACI recommendations for portland cement concrete, curing is required. Moist cure with wet burlap and polyethylene, a fine mist of water or a water based\* compatible curing compound. Curing compounds adversely affect the adhesion of following layers of mortar, leveling mortar or protective coatings. Moist curing should commence immediately after finishing. Protect newly applied material from direct sunlight, wind, rain and frost.

\*Pretesting of curing compound is recommended.

#### LIMITATIONS:

- ▲ Application thickness:  
Minimum 1/8 inch  
Maximum in one lift  
Vertical/Horizontal - 2 inches  
Overhead - 1 1/2 inches
- ▲ Minimum ambient and surface temperatures 45 F and rising at time of application.
- ▲ Do not use solvent-based curing compound.

#### CAUTION

**Irritant; Suspect Carcinogen** - Contains portland cement and sand (crystalline silica). Skin and eye irritant. Avoid contact. Dust may cause respiratory tract irritation. Avoid breathing dust. Use only with adequate ventilation. May cause delayed lung injury (silicosis). IARC lists crystalline silica as having sufficient evidence of carcinogenicity in laboratory animals and limited evidence of carcinogenicity in humans. NTP also lists crystalline silica as a suspect carcinogen. Use of safety goggles and chemical resistant gloves is recommended. If PELs are exceeded, an appropriate, properly fitted NIOSH/MSHA approved respirator is required. Remove contaminated clothing.

#### FIRST AID:

In case of skin contact, wash thoroughly with soap and water. For eye contact, flush immediately with plenty of water for at least 15 minutes, and contact a physician. For respiratory problems, remove person to fresh air.

#### CLEAN UP:

In case of spillage, scoop or vacuum into appropriate container, and dispose of in accordance with current, applicable local, state, and federal regulations. Keep container tightly closed and in an upright position to prevent spillage and leakage.

**Mixed components:** Uncured material can be removed with water. Cured material can only be removed mechanically.

Product Code 19M-500. Sika, Armatex, and MonoTop are registered trademarks. Made in USA. Printed in USA. March, 2000.

**KEEP CONTAINER TIGHTLY CLOSED  
NOT FOR INTERNAL CONSUMPTION**

**CONSULT MATERIAL SAFETY DATA SHEET FOR MORE INFORMATION**

**KEEP OUT OF REACH OF CHILDREN  
FOR INDUSTRIAL USE ONLY**

Sika warrants its products to be free from manufacturing defects and to meet Sika's current published properties when applied in accordance with Sika directions and tested in accordance with ASTM and Sika Standards. User determines suitability of product for use and assumes all risks. Buyer's sole remedy shall be limited to the purchase price or replacement of product and excludes labor or the cost of labor. Any claim for breach of this warranty must be brought within one year of the date of purchase.

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Quality Certification Numbers: Lyndhurst: 93-062B, Marion: 93-086B, Kansas City: 94-258B, Santa Fe Springs: 94-195C



Spec Component: SC-135-0500  
Sika MonoTop 615

**DIVISION 3 - CONCRETE**  
**Section 03730 Concrete Rehabilitation**

**Part 1 – General**

**1.01 Summary**

- A. This specification describes the patching of interior and/or exterior horizontal, vertical, or overhead surfaces with a silica fume, polymer-modified, portland cement mortar.

**1.02 Quality Assurance**

- A. Manufacturing qualifications: The manufacturer of the specified product shall be ISO 9001 certified and have in existence a recognized ongoing quality assurance program independently audited on a regular basis.
- B. Contractor qualifications: Contractor shall be a qualified in the field of concrete repair and protection with a successful track record of 5 years or more. Contractor shall maintain qualified personnel who have received product training by a manufacturer's representative.
- C. Install materials in accordance with all safety and weather conditions required by manufacturer or as modified by applicable rules and regulations of local, state and federal authorities having jurisdiction. Consult Material Safety Data Sheets for complete handling recommendations.

**1.03 Delivery, Storage, and Handling**

- A. All materials must be delivered in original, unopened containers with the manufacturer's name, labels, product identification, and batch numbers. Damaged material must be removed from the site immediately.
- B. Store all materials off the ground and protect from rain, freezing or excessive heat until ready for use.
- C. Condition the specified product as recommended by the manufacturer.

**1.04 Job Conditions**

- A. Environmental Conditions: Do not apply material if it is raining or snowing or if such conditions appear to be imminent. Minimum application temperature 45°F (5°C) and rising.
- B. Protection: Precautions should be taken to avoid damage to any surface near the work zone due to mixing and handling of the specified material.

**1.05 Submittals**

- A. Submit two copies of manufacturer's literature, to include: Product Data Sheets, and appropriate Material Safety Data Sheets (MSDS).

**1.06 Warranty**

- A. Provide a written warranty from the manufacturer against defects of materials for a period of five (5) years, beginning with date of substantial completion of the project.



## **Part 2 - Products**

### **2.01 Manufacturer**

- A. **Sika MonoTop 615**, as manufactured by Sika Corporation, is considered to conform to the requirements of this specification.

### **2.02 Materials**

- A. Silica-fume, Polymer-modified Portland cement mortar:
  - 1. The mortar shall be a silica fume enhanced, polymer-modified composition containing a blend of selected portland cements, specially graded aggregates, admixtures for plasticizing/water-reducers for workability, and monomers.
  - 2. The materials shall be non-combustible, both before and after cure.
  - 3. The materials shall be supplied in a factory-proportioned unit.
  - 4. The silica fume, polymer-modified, portland cement mortar must be placeable from 1/8" to 2" in depth per lift.

### **2.03 Performance Criteria**

- A. Typical Properties of the mixed polymer-modified, portland cement mortar:
  - 1. Working Time: Approximately 45 minutes
  - 2. Finishing Time: Approximately 60 minutes
  - 3. Color: concrete gray
- B. Typical Properties of the cured polymer-modified, portland cement mortar:
  - 1. Compressive Strength (ASTM C-109 Modified)
    - a. 1 day: 1500 psi min. (10.3 MPa)
    - b. 7 day: 3500 psi min. (24.1 MPa)
    - c. 28 day: 4300 psi min. (29.7 MPa)
  - 2. Flexural Strength (ASTM C-293) @ 28 days: 1000 psi (6.9 MPa)
  - 3. Splitting Tensile Strength (ASTM C-496) @ 28 days: 400 psi (2.8 MPa)
  - 4. Bond Strength (ASTM C-882 Modified) @ 28 days: 1000 psi (6.9 MPa)
  - 5. The silica fume, polymer-modified portland cement mortar shall not produce a vapor barrier.
  - 6. Density (wet mix): 104 lbs. / cu. ft. (1.65 kg/l)
  - 7. Permeability - AASHTO T-277 @ 28 days Approximately 600 Coulombs

**Note:** Tests above were performed with the material and curing conditions @ 71°F – 75°F and 45-55% relative humidity.

## Part 3 – Execution

### 3.01 Surface Preparation

- A. Areas to be repaired must be clean, sound, and free of contaminants. All loose and deteriorated concrete shall be removed by mechanical means. Mechanically prepare concrete substrate to obtain a surface profile of  $\pm 1/16"$  (CSP 5 or greater as per ICRI Guidelines) with a new exposed aggregate surface. Area to be patched shall not be less than  $1/8"$  in depth.
- B. Where reinforcing steel with active corrosion is encountered, sandblast the steel to a white metal finish to remove all contaminants and rust. Where corrosion has occurred due to the presence of chlorides, the steel shall be high pressure washed after mechanical cleaning. Prime steel with 2 coats of Sika Armatex 110 EpoCem as per the technical data sheet. (See Spec Component SC-201)

### 3.02 Mixing and Application

- A. Mechanically mix in an appropriate sized mortar mixer or with a Sika mud paddle and low speed (400-600 rpm) drill. Pour approximately  $4/5$  of 1 gallon of water into the mixing container. Add MonoTop 615 while continuing to mix. Mix to a uniform consistency for a maximum of three minutes. Add remaining water to mix for desired consistency. Should smaller quantities be needed, be sure the components are measured in the correct ratio and that the Sika MonoTop 615 is uniformly blended before mixing the components together. Mix only that amount of material that can be placed in 45 minutes. Do not retemper material.
- B. Placement Procedure: At the time of application, the substrate shall be saturated surface dry with no standing water. Mortar must be scrubbed into substrate filling all pores and voids. While the scrub coat is still plastic, force material against edge of repair, working toward center. If repair area is too large to fill while scrub coat is still wet use Sika Armatex 110 EpoCem in lieu of scrub coat. (See spec component SC-200) After filling, consolidate then screed. Allow mortar to set to desired stiffness then finish with trowel for smooth surface. Wood float or sponge float for a rough surface. Areas where the depth of the repair area to sound concrete is greater than 2", the repair shall be made in lifts of 2" maximum thickness. The top surface of each lift shall be scored to produce a rough surface for the next lift. The preceding lift shall be allowed to reach final set before applying fresh material. The fresh mortar must be scrubbed into the preceding lift.
- C. As per ACI recommendations for portland cement concrete, curing is required. Moist cure with wet burlap and polyethylene, a fine mist of water or a water-based\* compatible curing compound. Moist curing should commence immediately after finishing and continue for 48 hours. Protect newly applied material from rain, sun, and wind until compressive strength is 70% of the 28-day compressive strength. To prevent from freezing cover with insulating material. Setting time is dependent on temperature and humidity.  
  
\*Pretesting of curing compound is recommended.
- D. Adhere to all procedures, limitations and cautions for the silica fume, polymer-modified portland cement mortar in the manufacturers current printed technical data sheet and literature.

### 3.05 Cleaning

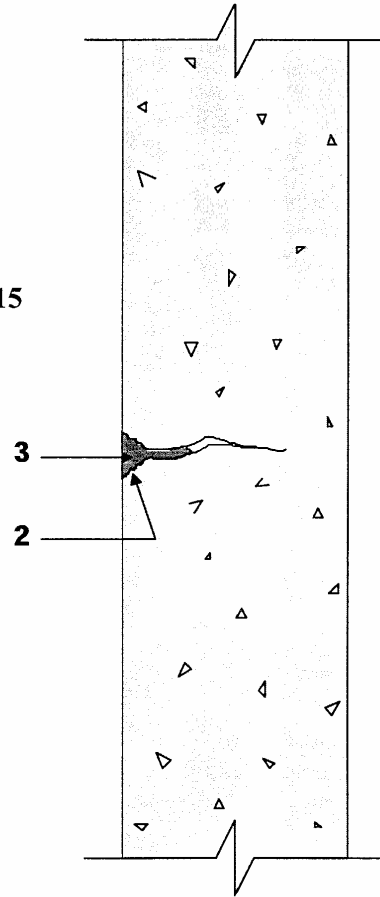
- A. The uncured silica fume, polymer-modified portland cement mortar can be cleaned from tools with water. The cured polymer-modified portland cement mortar can only be removed mechanically.
- B. Leave finished work and work area in a neat, clean condition without evidence of spillovers onto adjacent areas.

# SC-135

## Sika MonoTop® 615

### Crack Filler (Vertical / Overhead)

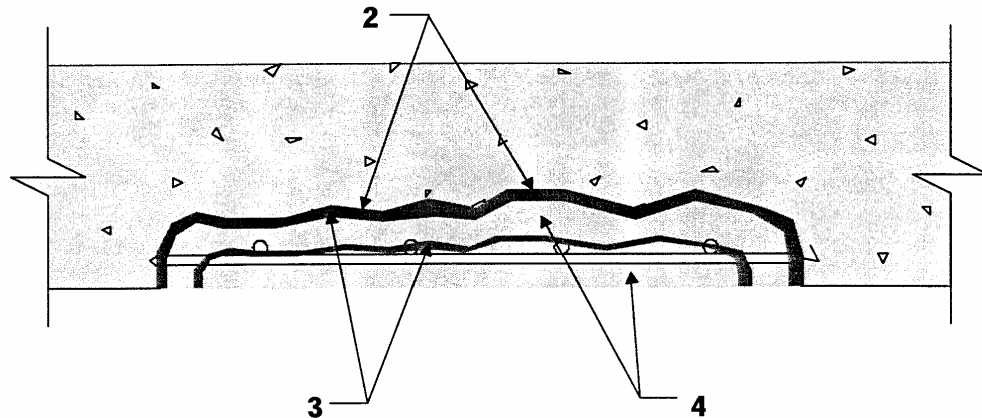
1. Repair area should be no less than 1/8" in depth.
2. Apply scrub coat to prepared substrate.
3. While scrub coat is still wet place **Sika MonoTop 615** filling the entire cavity.
4. Strike off and level as required.



Concrete Restoration Systems by Sika Corporation, 201 Polito Avenue, Lyndhurst, NJ 07071

## SC-135 Sika MonoTop® 615

### Hand-applied (Vertical / Overhead)



1. Repair area should not be less than  $\frac{1}{8}$ " in depth.
2. Substrate should be saturated surface dry (SSD) with no standing water during application.
3. Apply scrub coat to the substrate, filling all pores and voids.
4. While scrub coat is still wet apply **Sika MonoTop 615**.

**Note:** If repair area is too large to fill while scrub coat is still wet, use Sika Armatec 110 EpoCem in lieu of the scrub coat. (See Spec Component SC-200)

For applications greater than 2" in depth, apply **Sika MonoTop 615** in lifts. Score the top surface of each lift to produce a roughened surface for the next lift. Allow preceding lift to reach final set. Repeat from step 3.

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# SikaRepair® 222

3/02

**One-component, early strength gaining,  
cementitious patching material**

## DESCRIPTION

SikaRepair 222 is a one-component, early strength gaining, cementitious, patching material for horizontal repair of concrete.

## WHERE TO USE

- ▲ On grade, above and below grade on concrete and mortar.
- ▲ As a repair material for spalled horizontal concrete surfaces, walkways, ramps, steps, etc.

## ADVANTAGES

- ▲ Easy-to-use; just add water.
- ▲ Not a vapor barrier.
- ▲ Suitable for exterior and interior applications.
- ▲ Not flammable, non-toxic.
- ▲ Easily applied to clean, sound substrate.
- ▲ High early strengths.

## YIELD

Approximately 0.42 cu. ft.  
Approximately 0.62 cu.ft. (222+32 lbs. of 3/8" pea gravel)

## PACKAGING

50-lb. multi-wall bag.  
SikaLatex R - 1 gal. plastic jug; 4/carton,  
5 gal. pails

## HOW TO USE

### SURFACE PREPARATION

Remove all deteriorated concrete, dirt, oil grease and all bond inhibiting materials from surface. Preparation work should be done by high pressure water blast, scabbler, or other appropriate mechanical means to obtain an exposed aggregate surface with a minimum surface profile of  $\pm 1/8$  inch. (CSP-6). Saturate surface with clean water. Substrate should be saturated surface dry (SSD) with no standing water during application.

### PRIMING

For priming of reinforcing steel use Sika Armatec 110 EpoCem (consult Technical Data Sheet).

#### Concrete Substrate:

Prime the prepared substrate with a brush or sprayed applied coat of Sika Armatec 110 EpoCem (consult Technical Data Sheet). Alternately, a scrub coat of SikaRepair 222 can be applied prior to placement of the mortar. The repair mortar has to be applied into the wet scrub coat before it dries.

### MIXING

#### With water:

Wet down all tools and mixer to be used. Add approximately 6 pints of water to

## TYPICAL DATA FOR SIKAREPAIR 222 (Material and curing conditions @ 73F and 50% R.H.)

<b>SHELF LIFE</b>	One year in original, unopened bags.	
<b>STORAGE CONDITIONS</b>	Store dry at 40-95F (4-35C). <b>Condition material to 65-75 F before using.</b>	
<b>COLOR</b>	Concrete gray.	
<b>APPLICATION TIME</b>	Approximately 30 minutes.	
<b>FINISHING TIME</b>	50-120 minutes.	
<b>Note:</b> All times start after adding Component 'B' to Component 'A' and are highly affected by temperature, relative humidity, substrate temperature, wind, sun, and other jobsite conditions.		
<b>COMPRESSIVE STRENGTH (ASTM C109)</b>		<b>With undiluted Latex R</b>
<b>1 day</b>	1,800 psi (12.4 MPa)	2,300 psi (15.9 MPa)
<b>7 days</b>	4,000 psi (27.6 MPa)	4,500 psi (31.0 MPa)
<b>28 days</b>	5,000 psi (34.5 MPa)	5,500 psi
<b>FLEXURAL STRENGTH (ASTM C293)</b>		
<b>28 days</b>	750 psi (5.2 MPa)	1,200 psi (8.2 MPa)
<b>SPLITTING TENSILE STRENGTH (ASTM C496)</b>		
<b>28 days</b>	450 psi (3.1 MPa)	700 psi (4.8 MPa)
<b>BOND STRENGTH *(ASTM C882 MODIFIED)</b>		
<b>28 days</b>	2,000 psi (13.8 MPa)	2,000 psi (13.8 MPa)

\* Mortar scrubbed into substrate.

mixing vessel. Slowly add 1 bag of SikaRepair 222 while continuing to mix. Mechanically mix with a low-speed drill (400-600 rpm) and Sika paddle or in an appropriate size mortar mixer.

**With Latex R:** Pour 3/4 gallon of Sika Latex R into the mixing container. Slowly add powder and mix as above.

**With diluted Latex R:** Sika Latex R may be diluted up to 5:1 (water:Sika Latex R) for projects requiring minimal polymer-modification. Pour 3/4 gallon of the mixture into the mixing container. Slowly add powder and mix as above.

**SikaRepair 222 Concrete:** For applications greater than 1 inch depth, add a 3/8 inch coarse aggregate. Aggregate must be non-reactive (reference ASTM C1260, C227 and C289), clean, well-graded, saturated surface dry (SSD), have low absorption and high density, and comply with ASTM C33 size number 8 per Table 2. Addition rate must not exceed 32 lbs. of aggregate/bag of SikaRepair 222 (32 lbs. of 3/8 in. aggregate is approximately 2.5 to 3.0 gal. by loose volume of aggregate). **Water may be varied to achieve the desired consistency. Do not overwater.**

### APPLICATION AND FINISH

The prepared mortar must be scrubbed into the substrate, filling all pores and voids. Force material against edge of repair, working toward center. After filling repair, consolidate, then screed. Allow mortar to set to desired stiffness, then finish. Mixing, placing and finishing should not exceed 45 minutes maximum.

### CURING

As per ACI recommendations for portland cement concrete, curing is required. Moist cure with wet burlap and polyethylene, a fine mist of water or a water based, compatible curing compound. Curing compounds adversely affect the adhesion of following lifts of mortar, leveling mortar or protective coatings. Moist curing should commence immediately after finishing. Protect freshly applied mortar from direct sunlight, wind, rain and frost.



#### LIMITATIONS

##### ▲ Application thickness: (with water and diluted Latex R)

	Min.	Max. inches one lift
Neat	1/4 inch (6 mm)	1 inch (25 mm)
Extended	1 inch (25 mm)	4 inches (100 mm)

##### ▲ Application thickness: (with undiluted Latex R)

	Min.	Max. in one lift
Neat	1/8 in (3 mm)	1 inch (25 mm)
Extended	1 inch (25 mm)	4 inches (100 mm)

- ▲ Minimum ambient and surface temperatures 45F (7C) and rising at time of application.
- ▲ Addition of coarse aggregates may result in variations of the physical properties of the mortar.
- ▲ Use only potable water.
- ▲ Not intended for use as an overlay material.
- ▲ As with all cement based materials, avoid contact with aluminum to prevent adverse chemical reaction and possible product failure. Insulate potential areas of contact by coating aluminum bars, rails, posts etc. with an appropriate epoxy such as Sikadur Hi-Mod 32.

#### CAUTION

##### SIKA LATEX R - IRRITANT -

May cause skin/eye/respiratory irritation. Avoid breathing vapors. Use with adequate ventilation. Avoid skin and eye contact. Safety goggles and rubber gloves are recommended.

##### IRRITANT

**Suspect carcinogen** - Contains portland cement and sand (crystalline silica). Skin and eye irritant. Avoid contact. Dust may cause respiratory tract irritation. Avoid breathing dust. Use only with adequate ventilation. May cause delayed lung injury (silicosis). IARC lists crystalline silica as having sufficient evidence of carcinogenicity in laboratory animals and limited evidence of carcinogenicity in humans. NTP also lists crystalline silica as a suspect carcinogen. Use of safety goggles and chemical resistant gloves is recommended. If PELs are exceeded, an appropriate, properly fitted NIOSH/MSHA approved respirator is required. Remove contaminated clothing.

#### FIRST AID

In case of skin contact, wash thoroughly with soap and water. For eye contact, flush immediately with plenty of water for at least 15 minutes, and contact a physician. For respiratory problems, remove person to fresh air.

#### CLEAN UP

In case of spillage, scoop or vacuum into appropriate container, and dispose of in accordance with current, applicable local, state, and federal regulations. Keep container tightly closed and in an upright position to prevent spillage and leakage.

**Mixed components:** Uncured material can be removed with water. Cured material can only be removed mechanically.

Product Code 552. Sika, SikaRepair, and SikaLatex are registered trademarks. Made in USA. Printed in USA. March, 2002.

**KEEP CONTAINER TIGHTLY CLOSED  
NOT FOR INTERNAL CONSUMPTION**

**KEEP OUT OF REACH OF CHILDREN  
FOR INDUSTRIAL USE ONLY**

**CONSULT MATERIAL SAFETY DATA SHEET FOR MORE INFORMATION**

Sika warrants its products to be free from manufacturing defects and to meet Sika's current published properties when applied in accordance with Sika directions and tested in accordance with ASTM and Sika Standards. User determines suitability of product for use and assumes all risks. Buyer's sole remedy shall be limited to the purchase price or replacement of product and excludes labor or the cost of labor. Any claim for breach of this warranty must be brought within one year of the date of purchase.

**NO OTHER WARRANTIES EXPRESSED OR IMPLIED INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE SHALL APPLY. SIKA SHALL NOT BE LIABLE FOR ANY CONSEQUENTIAL OR SPECIAL DAMAGES OF ANY KIND, RESULTING FROM ANY CLAIM OF BREACH OF WARRANTY, BREACH OF CONTRACT, NEGLIGENCE OR ANY LEGAL THEORY. SIKA ASSUMES NO LIABILITY FOR USE OF THIS PRODUCT IN A MANNER TO INFRINGE ON ANOTHER'S PATENT.**

Visit our website at [www.sikausa.com](http://www.sikausa.com)

**1-800-933-SIKA NATIONWIDE**

**Regional Information and Sales Centers**

For the location of your nearest Sika sales office, contact your regional center.

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Quality Certification Numbers: Lyndhurst: 93-062B, Marion: 93-086B, Kansas City: 94-258B, Santa Fe Springs: 94-195C



"THE FIBRWRAP® COMPANY"

## Tyfo® SCH-35 Composite using Tyfo® S Epoxy

### DESCRIPTION

The Tyfo® SCH-35 Composite is comprised of Tyfo® S Epoxy and Tyfo® SCH-35 reinforcing fabric. Tyfo® SCH-35 is a custom stitched, uni-directional carbon fabric. The carbon material is orientated in the 0° direction. The Tyfo® S Epoxy is a two-component epoxy matrix material for bonding applications. Tyfo® S Epoxy may also be thickened and used as a prime or finish coat depending upon the project requirements.

### USE

Tyfo® SCH-35 Fabric is combined with Tyfo® epoxy to add strength to bridges, buildings, and other structures.

### ADVANTAGES

- Good high temperature properties
- Good low temperature properties
- Long working time
- High elongation
- Ambient cure
- 100% solvent-free
- Rolls can be cut to desired widths prior to shipping

### COVERAGE

Approximately 600 sq. ft. surface area with 3 to 4 units of Tyfo® S Epoxy and 1 roll of Tyfo® SCH-35 Fabric when used with the Tyfo® Saturator.

### PACKAGING

Order Tyfo® S Epoxy in 55-gallon (208L) drums or pre-measured units in 5-gallon (19L) containers. Tyfo® SCH-35 Fabric typically shipped in 2 rolls of 24" x 300 lineal foot (0.6m x 91.4m) rolls. Typically ships in 12" x 13" x 64" (305mm x 330mm x 1626mm) boxes.

### EPOXY MIX RATIO

100.0 component A to 42.0 component B by volume. (100 component A to 34.5 component B by weight.)

### SHELF LIFE

Epoxy - two years in original, unopened and properly stored containers.  
Fabric - ten years in proper storage conditions.

### STORAGE CONDITIONS

Store at 40° to 90° F (4° to 32° C). Avoid freezing. Store rolls flat, not on ends, at temperatures below 100° F (38° C). Avoid moisture and water contamination.

### CERTIFICATE OF COMPLIANCE

- Will be supplied upon request, complete with state and federal packaging laws with copy of labels used.
- Material safety data sheets will be supplied upon request.
- Possesses 0% V.O.C. level.

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### HOW TO USE

#### THE TYFO® S COMPOSITE SYSTEM

### DESIGN

The Tyfo® System shall be designed to meet specific design criteria. Design should comply with ICBO AC-125, and be based on tension force and strain limitations. Each project presents unique parameters that must be addressed. The Fyfe Co. LLC engineering staff will provide preliminary design at no obligation.

### INSTALLATION

Tyfo® System to be installed by Fyfe Co. LLC trained and certified applicators. Installation shall be in strict compliance with the Fyfe Co. LLC Quality Control Manual.

### SURFACE PREPARATION

The required surface preparation is largely dependent on the type of element being strengthened. In general, the surface must be clean, dry and free of protrusions or cavities, which may cause voids behind the Tyfo® composite. Column surfaces that will receive continuous wraps typically require only a broom cleaning. Discontinuous wrapping surfaces (walls, beams, slabs, etc.) typically require a light sandblast, grinding or other approved methods to prepare for bonding. Mechanical anchors are incorporated in some designs. The Fyfe Co. LLC engineering staff will provide the proper specifications and details based on the project requirements.

### MIXING

For pre-measured units in 5-gallon containers, pour the contents of component B into the pail of component A. For drums, premix each component: 100.0 parts of component A to 42.0 parts of component B by volume (100 parts of component A to 34.5 parts of component B by weight). Mix thoroughly for five minutes with a Tyfo® low speed mixer at 400-600 RPM until uniformly blended.

### APPLICATION

Feed fabric through the Tyfo® Saturator and apply using the Tyfo® wrapping equipment or approved hand methods (see data sheet on this equipment). Hand saturation is allowable, provided the epoxy is applied uniformly and meets the specifications.

### LIMITATIONS

Minimum application temperature of the epoxy is 40° F (4° C). **DO NOT** thin, solvents will prevent proper cure.

#### COMPOSITE LAMINATE PROPERTIES

PROPERTY	ASTM METHOD	TYPICAL TEST VALUE*
Ultimate tensile strength in primary fiber direction, psi	D-3039	143,700 psi (991 MPa) (5.0 kip/in. width)
Elongation at break, min.	D-3039	1.26%
Tensile Modulus, psi	D-3039	11.4 x 10 <sup>6</sup> psi (78.6 GPa)
Ultimate tensile strength 90 degrees to primary fiber, psi	D-3039	0
Laminate Thickness (normalized)		0.035 in. (0.89mm)

\* Design and specification values will vary based on individual project requirements and applicable safety factors. Contact Fyfe Co. LLC engineering to determine appropriate specification values.

EPOXY MATERIAL PROPERTIES		
Curing Schedule 72 hours post cure at 140° F (60° C).		
	ASTM METHOD	TYPICAL TEST VALUE*
T <sub>g</sub> 140° F (60° C) Post Cure (24 hours)		180° F (82° C)
Tensile Strength <sup>1</sup>	ASTM D-638 Type 1	10,500 psi (72.4 MPa)
Tensile Modulus		461,000 psi (3.18 GPa)
Elongation Percent	ASTM D-638 Type 1	5.0%
Flexural Strength	ASTM D-790	17,900 psi (123.4 MPa)
Flexural Modulus	ASTM D-790	452,000 psi (3.12 GPa)

<sup>1</sup> Testing temperature: 70° F (21° C)    Crosshead speed: 0.5 in. (13mm)/min.    Grips Instron 2716-0055 - 30 kips  
\* Specification values can be provided upon request.

#### CAUTION!

##### COMPONENT A - Irritant:

Prolonged contact to the skin may cause irritation. Avoid eye contact.

##### COMPONENT B - Irritant:

Contact with skin may cause severe burns. Avoid eye contact. Product is a strong sensitizer. Use of safety goggles and chemical resistant gloves recommended. Remove contaminated clothing. Avoid breathing vapors. Use adequate ventilation. Use of an organic vapor respirator recommended.

##### SAFETY PRECAUTIONS

Use of an approved peroxide mask is recommended for possible airborne particles. Gloves are recommended when handling fabrics to avoid skin irritation. Safety glasses are recommended to prevent eye irritation.

##### FIRST AID

In case of skin contact, wash thoroughly with soap and water. For eye contact, flush immediately with plenty of water; contact physician immediately. For respiratory problems, remove to fresh air. Wash clothing before reuse.

##### CLEANUP

Collect with absorbent material, flush with water. Dispose of in accordance with local disposal regulations. Uncured material can be removed with approved solvent. Cured materials can only be removed mechanically.

##### TYFO® S COMPOSITE SAMPLES

Please note that field samples are to be cured for 48-hours at 140° F (60° C) before testing. Testing shall be in accordance with ASTM D-3039 and the Fyfe Co. LLC sample preparation and testing procedures.

##### SHIPPING LABELS CONTAIN

- State specification number with modifications, if applicable
- Component designation
- Type, if applicable
- Manufacturer's name
- Date of manufacture
- Batch name
- State lot number, if applicable
- Directions for use
- Warnings or precautions required by law

KEEP CONTAINER TIGHTLY CLOSED.  
NOT FOR INTERNAL CONSUMPTION.  
CONSULT MATERIAL SAFETY DATA SHEET (MSDS) FOR MORE INFORMATION.  
KEEP OUT OF REACH OF CHILDREN.  
FOR INDUSTRIAL USE ONLY.

## Fyfe Co. LLC

"The Fibwrap® Company"

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3/01 Tyfo® 8CH-35

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"THE FIBRWRAP® COMPANY"

## Tyfo® S Saturant Epoxy

### DESCRIPTION

The Tyfo® S Epoxy is a two-component epoxy matrix material for bonding applications. It is a high elongation material which gives optimum properties as a matrix for the Tyfo® Fibrwrap System. It provides a long working time for application, with no offensive odor. Tyfo® S Epoxy may also be thickened and used as a prime or finish coat depending upon the project requirements.

### USE

The Tyfo® S Epoxy matrix material is combined with the Tyfo® fabrics to provide a wet-layup composite system for strengthening structural members.

### ADVANTAGES

- \* Good high temperature properties
- \* Good low temperature properties
- \* Long working time
- \* High elongation
- \* Ambient cure
- \* 100% solvent-free

### COVERAGE

Approximately 0.8 pounds of epoxy per 1.0 pound of fabric when our Tyfo® Saturator is used. When used as a prime coat the coverage is highly dependent upon the existing surface.

### PACKAGING

Order in 55-gallon drums or pre-measured units in 5-gallon containers.

### MIX RATIO

100.0 parts of component A to 42.0 parts of component B by volume. (100 parts of component A to 34.5 parts of component B by weight.)

### SHELF LIFE

Two years in original, unopened and properly stored containers.

### STORAGE CONDITIONS

Store at 40° to 90° F (4° to 32° C). Avoid freezing.

### CERTIFICATE OF COMPLIANCE

- \* Will be supplied upon request, complete with state and federal packaging laws with copy of labels used.
- \* Material safety data sheets will be supplied upon request.
- \* Possesses 0% V.O.C. level, per ASTM D-2369.

400 Tyfo® S

### HOW TO USE THE TYFO® S EPOXY

#### INSTALLATION

Tyfo® System to be installed by Fyfe Co. LLC trained and certified applicators. Installation shall be in strict compliance with the Fyfe Co. LLC Quality Control Manual.

#### SURFACE PREPARATION

The required surface preparation is largely dependent on the type of element being strengthened. In general, the surface must be clean, dry and free of protrusions or cavities, which may cause voids behind the Tyfo® composite. Column surfaces that will receive continuous wraps typically require only a broom cleaning. Discontinuous wrapping surfaces (walls, beams, slabs, etc.) typically require a light sandblast, grinding or other approved methods to prepare for bonding. Mechanical anchors are incorporated in some designs. The Fyfe Co. LLC engineering staff will provide the proper specifications and details based on the project requirements.

#### MIXING

For pre-measured units in 5-gallon containers, pour the contents of component B into the pail of component A. For drums, premix each component: 100.0 parts of component A to 42.0 parts of component B by volume (100 parts of component A to 34.5 parts of component B by weight). If material is too thick, drum heaters may be used on metal containers, or heat unmixed components by placing containers in 130° F (54° C) tap water or sunlight, if available, until the desired viscosity is achieved. Do not thin; solvents will prevent proper cure. Mix thoroughly for five minutes with a low speed mixer at 400-600 RPM until uniformly blended. When using as a prime coat or finish coat, Tyfo® S Epoxy may be thickened in the field to the desired consistency.

#### APPLICATION

Tyfo® S Epoxy is applied to a variety of Tyfo® fabrics using the Tyfo® Saturator or by approved hand-applied methods. See data sheet on this equipment. Hand saturation is allowable, provided the epoxy is applied uniformly and meets the specifications. Tyfo® S Epoxy can also be applied as a prime coat by brush or roller.

#### LIMITATIONS

Minimum application temperature of the epoxy is 40° F (4° C). **DO NOT THIN**; solvents will prevent proper cure.

#### EPOXY COMPONENT PROPERTIES

Color	Component A is clear to pale yellow Component B is clear
Viscosity	Component A at 77° F (25° C) is 11,000-13,000 cps ASTM D-2392-80. Component B at 77° F (25° C) is 11 cps ASTM D-2393-80.
Pot Life	3 to 6 hours at 68° F (20° C).
Viscosity of Mixed Product	600-700 cps.
Density at 68° F (20° C) (Pound/Gallon)	Component A = 9.7 (4.4kg/3.79L) Component B = 7.9 (3.6kg/3.79L) Mixed product = 9.17 (4.2kg/3.79L)

EPOXY MATERIAL PROPERTIES		
Curing Schedule 72 hours post cure at 140° F (60° C).		
PROPERTY	ASTM METHOD	TYPICAL TEST VALUE*
Tg 140°F (60°C) Post Cure (24 hours)		180°F (82°C)
Tensile Strength <sup>1</sup> , psi	ASTM D-638 Type 1	10,500 (72.4 MPa)
Tensile Modulus, psi		461,000 (3.18 GPa)
Elongation Percent	ASTM D-638 Type 1	5.0%
Flexural Strength, psi	ASTM D-790	17,900 (123.4 MPa)
Flexural Modulus, psi	ASTM D-790	452,000 (3.12 GPa)

<sup>1</sup> Testing temperature: 70°F (21°C) Crosshead speed: 0.5 in. (13mm)/min. Grip fixture 2716-0050 - 30 kpsi

\* Specification values can be provided upon request.

#### CAUTION!

**COMPONENT A - Irritant:**  
Prolonged contact to the skin may cause irritation. Avoid eye contact.

**COMPONENT B - Irritant:**  
Contact with skin may cause severe burns. Avoid eye contact. Product is a strong sensitizer. Use of safety goggles and chemical resistant gloves recommended. Remove contaminated clothing. Avoid breathing vapors. Use adequate ventilation. Use of an organic vapor respirator recommended.

#### FIRST AID

In case of skin contact, wash thoroughly with soap and water. For eye contact, flush immediately with plenty of water; contact physician immediately. For respiratory problems, remove to fresh air. Wash clothing before reuse.

#### CLEANUP

Collect with absorbent material, flush with water. Dispose of in accordance with local disposal regulations. Uncured material can be removed with approved solvent. Cured materials can only be removed mechanically.

#### SHIPPING LABELS CONTAIN

- State specification number with modifications, if applicable
- Component designation
- Type, if applicable
- Manufacturer's name
- Date of manufacture
- Batch name
- State lot number, if applicable
- Directions for use
- Warnings or precautions required by law

**KEEP CONTAINER TIGHTLY CLOSED.  
NOT FOR INTERNAL CONSUMPTION.  
CONSULT MATERIAL SAFETY DATA SHEET  
(MSDS) FOR MORE INFORMATION.  
KEEP OUT OF REACH OF CHILDREN.  
FOR INDUSTRIAL USE ONLY.**

## Fyfe Co. LLC

"The Fibrwrap Company"

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4/00 Tylo® 8

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"THE FIBRWRAP® COMPANY"

## Tyfo® 103 Regular Injection Epoxy

### DESCRIPTION

Tyfo® 103 Regular Injection Epoxy is a two-component, standard viscosity, high modulus epoxy adhesive.

### USE

Recommended for the repair of cracks in concrete with automatic meter, mix and dispense pressure injection equipment.

### ADVANTAGES

- Good high temperature properties
- Resistance to creep and stress relaxation
- Excellent adhesion under adverse application conditions (cold, wet concrete)

### PACKAGING

Order in 150-gallon or 15-gallon units.

### MIX RATIO

Two parts component A to 1 part component B by volume; 100:43 by weight.

### SHELF LIFE

Three years in original, unopened and properly stored containers.

### STORAGE CONDITIONS

Store at 40° to 90° F (4° to 32° C) away from sunlight in a dry place. Avoid freezing.

### CERTIFICATE OF COMPLIANCE

- Will be supplied upon request, complete with state and federal packaging laws with copy of labels used.
- Material safety data sheets will be supplied upon request.

### HOW TO USE

#### TYFO® 103 INJECTION EPOXY

### SURFACE PREPARATION

The concrete must be sound and free of all bond-inhibiting substances. Accumulations of water must be removed with compressed, oil-free air.

### MIXING

Tyfo® 103 is a two-component system designed specifically for use with automatic meter, mix and dispense equipment. Mix ratio is 2 parts of component A to 1 part of component B by volume. Application equipment should be routinely checked daily to determine that the equipment is metering and proportioning the components accurately and is delivering thoroughly mixed material.

### APPLICATION

Apply material in accordance with established industry procedures. Use only trained personnel with experience in pressure injection application. Allow for adequate cure of the epoxy adhesive before the repaired structure is returned to service.

### LIMITATIONS

The recommended minimum substrate temperature during installation is 50° F (10° C). The maximum sustained in-service temperature of fully cured material is approximately 120° F (49° C) in applications where substantial and sustained shear stresses are encountered. The material is not recommended for application in wide cracks above 80° F (27° C). The installed thickness should not exceed 0.25-inch unless preplaced aggregate is used to dissipate heat generated during the curing process.

#### EPOXY MATERIAL PROPERTIES

Curing Schedule, 7 days at 73° F (23° C) +/4° F.

Test temperature, 73° F (23° C) +/4° F, unless otherwise specified.

PROPERTY	ASTM METHOD	TYPICAL TEST VALUE*
Density (Pound/Gallon)	D-1475	Part A = 9.4 (4.3kg) Part B = 8.1 (3.7kg) Mixed = 9.0 (4.1kg)
Viscosity, cps	D-2393	Part A 420 Part B 160 Mixed 360
Viscosity @ 50°F (10°C), cps	D-2393	Mixed 1,450
Gel Time, 5 minutes	C-881-90	14 minutes
Tensile Strength, psi	D-638	9,000 (62.1 MPa)
Elongation at Break, Percent	D-695	2.0%
Compressive Yield Strength, psi	D-695	16,000 (110.3 MPa)
Compressive Modulus, psi	D-648	400,000 (2.8 GPa)
Heat Deflection Temperature, F (C)	AASHTO T-237	140° F (60° C)
Wet Slant Shear Strength <sup>1</sup>		Cement Mortar Failure <sup>2</sup>

(1) Cure schedule, 7 days at 40° F (4° C).

(2) Compressive strength of cement mortar, >4,500 psi.

Note: Tyfo® 103 Regular Injection Epoxy meets or exceeds the properties of a material specified in ASTM C-881-90 Type I and IV, Grade 1.

\* Specification values can be provided upon request.

301 Tyfo® 103

#### CAUTION!

**COMPONENT A** - Liquid epoxy resin, HMIS Health Hazard Rating: 2 (Moderate Hazard). Causes skin and eye irritation. May cause allergic reaction. Harmful if swallowed. Avoid contact with eyes, skin and clothing. Wash thoroughly after handling. Avoid prolonged or repeated contact with skin.

**COMPONENT B** - Liquid epoxy hardener, HMIS Health Hazard Rating: 3 (Serious Hazard). Contains alkaline amines. Danger! Corrosive liquid. Causes severe eye and skin burns. May cause allergic skin and respiratory reaction. Do not get in eyes, on skin or clothing. Avoid breathing vapor. Keep container closed when not in use. Use only with adequate ventilation. Wash thoroughly after handling. Combustible. Keep away from heat or open flame.

#### SAFETY PRECAUTIONS

Use of an approved respirator is recommended for possible contact with vapor. Rubber gloves are recommended when handling this material to avoid skin irritation. Safety glasses are recommended to prevent eye irritation.

#### FIRST AID

In case of skin contact, wash thoroughly with soap and water. For eye contact, flush immediately with plenty of water; contact physician immediately. For respiratory problems, remove to fresh air. Wash clothing before reuse.

#### CLEANUP

Collect with absorbent material, flush with water. Dispose of in accordance with local disposal regulations. Uncured material can be removed with approved solvent. Cured materials can only be removed mechanically.

#### SHIPPING LABELS CONTAIN

- State specification number with modifications, if applicable
- Component designation
- Type, if applicable
- Manufacturer's name
- Date of manufacture
- Batch name
- State lot number, if applicable
- Directions for use
- Warnings or precautions required by law

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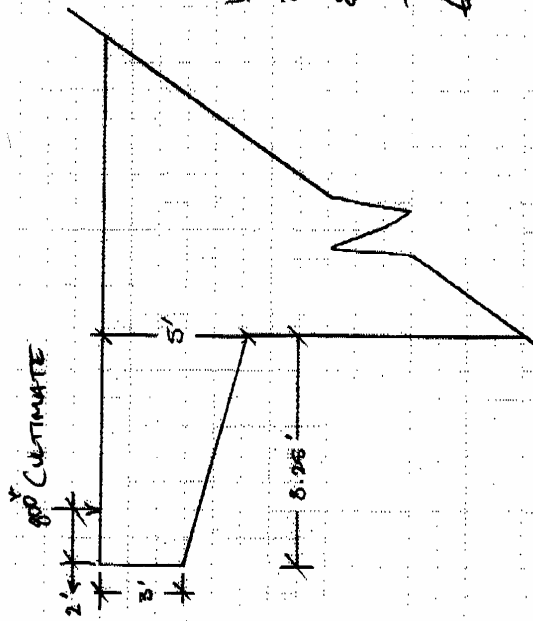
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3/01 Tyfo® 103

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## BYU OUTRIGGER BENTS



DESIGN GOAL: PROVIDE ADDITIONAL TENSILE CAPACITY TO ACCOMMODATE A 800' POINT LOAD 2' FROM CANTILEVER END.  
 ⇒ ULTIMATE DESIGN.

USE SCH 38 CARBON COMPOSITE

$E_j = 9000 \text{ ksi}$  MIN (TENSILE MODULUS)

$\epsilon_j = 0.004$  (ULTIMATE ALLOWABLE STRAIN)

$f_j = E_j \epsilon_j = 27 \text{ ksi}$  (ALLOWABLE STRESS)

$t_j = 0.035$ " PER LAYER OF COMPOSITE

GIVEN TENSILE MATERIALS:

TOP STEEL → 9-#8 GRADE 40 BARS (2" COVER)

BOTTOM STEEL → 7-#8 GRADE 40 BARS

SHEAR REINFORCING → 2 LEGS OF #5 GRADE 40 BARS @ 6" ON CENTERS

⇒ NOTE: BY RESTRICTING ALLOWABLE STRAINS TO 0.004 IN THE COMPOSITE LOCATED AT THE PIER TOP AGGREGATE INTERLOCK, STEEL RESERVE STRENGTH AND BEAM DEPTH WILL RESTRICT SHEAR DAMAGE.

REPORTED AS-BUILT PERFORMANCE:

ULTIMATE SUSTAINABLE LOAD: 709 K

CRACK DETECTION @  $\sim 100$  K (@  $E_c = 0.003$ )

CRACK WIDENING FROM 550-600 K

$\Rightarrow$  ROUGH CORRESPONDING MOMENTS

$\Rightarrow$  ASSUME A LEVER ARM OF 5' FOR TOP STEEL, 2' FOR BOTTOM STEEL.

$$M_{PER} \approx 6.25' (800 \text{ K})$$

$$\text{ASSUME } M_{TOT} = (8.25' - 2') (P)$$

$$= 5,000 \text{ KIP-FT}$$

$$@ 400 \text{ SAM } E = 0.003$$

$$\text{ASSUME AT } P = 500 \text{ K } E_c \approx 0.004$$

ASSUME EXISTING CAPACITY IS

$$M_{EXIST} (@ E_c = 0.004) = \boxed{3,125 \text{ K-FT}}$$

COMPOSITE IS 24" WIDE, LEVER ARM FOR MOMENT WOULD BE

$$5' - (2\frac{1}{2}') = 4'$$

$$M_{COMPOSITE} = M_{PER} - M_{EXIST} = (5,000 - 3,125) \text{ K-FT}$$

$$= 1,875 \text{ KIP-FT}$$

$$M_{COMPOSITE} = (4') T_{COMP}$$

$$T_{comp} = A_{comp} f_{com} = w_{com} t_{com} f_{com} = (24'')(t_{com})(27 \text{ ksi.})(2 \text{ SIDES})$$

$$\Rightarrow 1,875 \text{ KIP-FT} = 24''(t_{com})(27 \text{ ksi.})(1')(2 \text{ SIDES})$$

$$22,500 \text{ K-IN} = (24'')(t_{com})(27 \text{ ksi.})(48'')(2 \text{ SIDES})$$

$$t_{com} \geq 0.361 \text{ IN} @ 0.055 = 11 \text{ LAYERS} \Rightarrow \text{SUBSTANTIAL}$$

$\Rightarrow$  DESIGN BASED ON HIGHER ALLOWABLE STRAINS:

$$\text{ALLOW STRAINS TO } 0.006 \Rightarrow f = 54 \text{ ksi.}$$

$$M_{PER} - M_{EXIST} = 5,000 - 4,431 = 570 \text{ KIP-FT}$$

$$570 \text{ KIP-FT} = \overset{w_j}{(24'' \text{ WIDE})} \overset{f_j}{(54 \text{ ksi.})} \overset{j_d}{(48'')}$$

$$t_j \geq 0.110 \text{ IN} \Rightarrow \boxed{4 \text{ LAYERS SET } 35}$$

$\Rightarrow$  EXAMINE AS-BUILT TEST TO EVALUATE ACCEPTABLE STRAIN LEVEL IN COMPOSITE.

$$\text{CONSERVATIVE} \Rightarrow E_u = 0.004 \Rightarrow 11 \text{ LAYERS}$$

$$\text{MAXIMUM} \Rightarrow E_u = 0.006 \Rightarrow 4 \text{ LAYERS}$$

*Pu*





Products & Systems for Architectural Concrete Finishes & Concrete Restoration

**THIN-FINISH™ Overlay is a high strength, cementitious topping material and bond coat designed for thin patching, resurfacing, overlaying, reducing surface defects and texturing stable concrete floors and surfaces.**

#### 1. DESCRIPTION and USES:

THIN-FINISH™ Overlay is formulated and engineered to provide a strong, durable interior or exterior finish to existing concrete surfaces.

THIN-FINISH™ Overlay is a pre-packaged, "just add water", overlay material consisting of hybrid redispersible polymers, graded quartz aggregates and white or gray portland cement to create a trowelable, polymer cement overlay material that cures to create a hard, abrasion resistant wear surface.

THIN-FINISH™ Overlay is designed to create durable finishes for concrete thin patching, resurfacing, overlaying, reducing surface defects, texturing stable concrete floors and surfaces or chemical staining of the surface is desired and is used to restore existing concrete floors and surfaces. Typical applications include interior or exterior commercial, industrial and residential concrete surfaces for renovation or new construction.

THIN-FINISH™ Overlay is also used as the base coat to nearly all overlay applications including but not limited to: TEXTURE-PAVE™ as a base coat and as a bond coat, MICRO-FINISH™ as a base coat and level coat.

THIN-FINISH™ Overlay offers many advantages over most overlay materials including better abrasion resistance, higher levels of strength and durability, excellent weather resistance such as resistance to moisture, UV and freeze/thaw cycles and is available in a wide variety of colors and color combinations. It can effectively be applied from 1/32" (0.75 mm) to 1/8" (3 mm) thick with a cured compressive strength exceeding 4,500 psi (31 MPa) after 28 days, allowing heavy commercial traffic without wear or damage.

THIN-FINISH™ Overlay is designed to be extremely easy to mix and install while proving very economical and cost effective. Once the surface has been properly cleaned and prepared, simply add the material to the recommended water volume, mix well and apply. It is designed to give a longer workability time compared to most other materials to ensure proper finishing and attention to detail.

THIN-FINISH™ Overlay can be applied by trowel, broom, neoprene squeegee or spray

with an air supplied hopper gun and can effectively be layered to create additional thickness when needed. Additional benefits as compared to concrete include increased flexural strength which decreases the brittleness of the surface and increased resistance to moisture, for above or below grade applications.

To add stain resistance or to make the finish easy to clean, THIN-FINISH™ Overlay must be initially and periodically sealed with approved and suitable Elite Crete Systems sealers. Additional information is available in the Elite Crete Systems Technical Data TD-414 SEALER OPTIONS.

#### 2. LIMITATIONS:

One single coat of THIN-FINISH™ Overlay is never sufficient for any application. If only one coat is applied, the adhesion and abrasion resistance of the finish will fail.

THIN-FINISH™ Overlay is engineered and designed for structurally sound, stable concrete surfaces. Not all concrete surfaces are suitable for the installation of THIN-FINISH™. Those surfaces which are not suitable include: concrete that has not cured for at least 28 days. Concrete with Vapor emission problems. Surfaces which are gypsum based and lightweight concrete. THIN-FINISH™ Overlay surfaces are not intended for use in areas subject to metal wheels, track or rollers.

THIN-FINISH™ Overlay is not intended for use in areas subject to water immersion or water leaks. If installation is desired in areas of harsh chemicals, testing and/or special coatings may be required.

THIN-FINISH™ Overlay is not intended for use as a crack repair product. Existing cracks must be repaired and all existing expansion joints must be honed.

All concrete surfaces must be properly cleaned and prepared. Failure to remove contaminants or existing coating may result in loss of adhesion, delamination and product failure. Any repairs or regrading must be completed prior to the application of the THIN-FINISH™ Overlay application. For repairs or regrading deeper than 1" (25 mm), multiple applications of TEXTURE-PAVE™ may be required. Allow the first application to dry prior to the application of the second mix. Additional information is available in the Elite Crete Systems Product Information PI-301 TEXTURE-PAVE™ Overlay.

To ensure proper product performance and aesthetics, accurately measure recommended water amounts. Increased water amounts will create whitening, surface cracking and decrease adhesion.

## PRODUCT INFORMATION: THIN-FINISH™ Overlay 03360 – Concrete Finishes

PI-302 - Revised 2/02  
Page 1

Recommended application temperature for THIN-FINISH™ Overlay is between 40° and 90° F (4° and 32° C). Ideal application temperature for THIN-FINISH™ Pre-Mixed Overlay is 70° F (21° C). If the ambient temperature is forecast to drop below 40° F (4° C) within 36 hours after the application of THIN-FINISH™ Overlay must not be installed.

#### 3. APPLICATION STANDARDS:

Professional standards and practices, including those published by the American Concrete Institute (ACI), the Portland Cement Association (PCA), and the International Concrete Repair Institute should be understood and followed.

#### 4. PRODUCT COMPOSITION:

THIN-FINISH™ Overlay is a precisely formulated and engineered, hybrid polymer modified cementitious mixture designed and manufactured with highly proprietary techniques.

#### 5. TECHNICAL DATA:

Compressive, flexural and tensile strengths as well as other performance test data concerning THIN-FINISH™ Overlay is listed in the table below. All properties are typical of those obtained when professionally tested by standard ASTM testing methods.

PROPERTY	RESULT
1. Compressive Strength 1 Day 7 Days 28 Days	1300 psi 2790 psi 4800 psi
2. Flexural Strength 7 Days 28 Days	990 psi 1490 psi
3. Tensile Strength 7 Days 28 Days	350 psi 750 psi
4. Abrasion Loss 28 Days	.17%
5. Density 7 Days 28 Days	1.17 g/cm <sup>3</sup> 1.88 g/cm <sup>3</sup>
6. Shear Bond 7 Days 28 Days	335 psi 575 psi
7. Cohesive 7 Days 28 Days	52 psi 98 psi
8. Impact Resistance 7 Days 28 Days	18 inch-lbs. 28 inch-lbs.

Different application thickness' and uses were tested for specific applications, but are not represented in the Test Data due to variations in mix design or specific application techniques and uses which changes the test results considerably. Variables include; density, water ratio, polymer ratio, aggregate size, application thickness, aggregate ratio to cement, aggregate composition, application tool/technique, drying temperature, environment, curing temperature & humidity.

**8. COLOR and COLORING:**

THIN-FINISH™ Overlay is available from stock integrally colored white or gray. If additional integral color is needed, use Portion Control Colorant™ available in 30 base colors designed for use with white base.

The use of ULTRA-STONE™ Stain is recommended for textured finishes to add natural color variations. The use of CHEM-STONE™ Stain is recommended for smooth or less textured finishes to add a mottled, aged look. ULTRA-STONE™ Stain may also be used on top of CHEM-STONE™ Stain to increase the color variations even more. As always, when applying any stain or color, it is highly recommended to experiment to ensure the proper color will be achieved. THIN-FINISH™ may be stained with ULTRA-STONE™ Stain once the surface is firm enough to take foot traffic and has cured 8 to 12 hours. THIN-FINISH™ may be stained with CHEM-STONE™ Stain once the surface has cured 16 to 24 hours. Note: If THIN-FINISH™ has not been allowed to cure 14 days, CHEM-STONE™ may not achieve maximum color intensity.

**7. PACKAGING:**

THIN-FINISH™ is available from stock in 55 Lb. (25 kg) bags.

**8. SHELF LIFE:**

Under normal, dry conditions the average shelf life of THIN-FINISH™ is six to nine months from date of purchase. Do not store directly on floors or open to weather. Rotate stock upon receipt and use.

**9. COVERAGE:**

Under normal conditions THIN-FINISH™ 55 Lb. (25 kg) bag will cover 110 to 180 sq. ft. at a depth of 1/16" (1.5 mm). Note: Coverage will vary depending on depth of fill or variation, surface texture or profile, preparation procedures used, desired surface finish and other conditions.

**10. CAUTIONS:**

**WARNING! IRRITATING TO EYES AND SKIN. DO NOT BREATHE DUST. MAY CAUSE DELAYED LUNG INJURY (SILICOSIS). CONTAINS CEMENT AND SILICA (QUARTZ).** Use with adequate ventilation. Wet cement may cause alkali burns. Dust mask (NIOSH/MSHA TC 21C approved), safety goggles and protective gloves are recommended.

**FIRST AID:** Eyes – DO NOT RUB EYES. Immediately flush thoroughly with plenty of clean water. Skin – Wash thoroughly with soap and water. Inhalation – Move to fresh air. If symptoms persist or develop, or if ingested, seek immediate medical attention. DO NOT TAKE INTERNALLY. KEEP OUT OF THE REACH OF CHILDREN. Before using or handling, read the Material Safety Data Sheet and Warranty.

**11. JOBSITE SUITABILITY:**

The application of THIN-FINISH™ requires skill and practice. Aspects such as preparation procedures, ambient and surface temperatures, mixing, installation, finishing and curing techniques, experience

in the use of the material and other factors will effect the long term performance of the overlay. Select a small section of the job and install a small test area of THIN-FINISH™ to ensure suitability of the substrate.

This test area should be of adequate size to be a true representative. This test area should be installed by the installers who will be installing the actual application and under the same conditions to ensure proper comparison. Once the test area has been installed, the surface should be tested for safety reasons to ensure the surface is of adequate wet and dry slip resistance.

**12. EQUIPMENT and MATERIALS:**

Protective equipment and clothing in accordance with government regulations, manufacturer instructions and all local, state and federal safety regulations must be used during the preparation and application of any Elite Crete Systems product.

Proper surface preparation is critical for permanent and successful overlay applications. THIN-FINISH™ is typically installed in one or two applications by means of troweling, screed, spraying or pumping directly onto the prepared surface and "bond coat".

For proper substrate preparation, use wire brushing, grinding, scarifying, shotblasting, sandblasting or other suitable equipment to remove laitance, coatings, curing compounds and other contaminants that interfere with adhesion. After roughening the concrete surface, sweep or vacuum all debris and follow with a thorough cleaning using a high-pressure water washer. Refer to International Concrete Repair Institute (ICRI) Guideline Number 03732 which specifies a Concrete Surface Profile (CSP) between Number 5 and Number 9.

For measuring, a container suitable for accurately measuring various water quantities should be used.

For mixing, a five-gallon bucket and a heavy duty drill with paddle type mixing blade should be used for small jobs and a mortar mixer is recommended for larger projects. Proper mixing can not be achieved mixing by hand or in a wheel barrel.

For spray/plaster applications a drywall type hopper gun powered by a continuous, oil free air compressor is recommended for smaller jobs. The use of a pressure pot type spraying unit is recommended for larger applications.

Other necessary tools include: neoprene squeegee, hand trowel and joint tool.

**13. SURFACE PREPARATION:**

Before installation a test area must be produced as described in 11. JOBSITE SUITABILITY. Concrete must be cured a minimum of 28 days prior to the application of any overlay.

Surrounding areas should be protected from tracking, spills and equipment contact. The

work area should be roped off and closed to traffic.

The most common overlay failure is improper surface preparation. The concrete must be structurally sound and prepared as recommended in the International Concrete Repair Institute (ICRI) Guideline Number 03732, Concrete Surface Profile (CSP) between Number 5 and Number 9, using equipment as described in 12. EQUIPMENT and MATERIALS.

Prior to installing THIN-FINISH™ as a "bond coat", all loose material, laitance, coatings, curing compounds, grease, oil, dirt, paint and other contaminants that interfere with adhesion must be completely removed using equipment as described in 12. EQUIPMENT and MATERIALS. The cleaning method to be used depends on the condition of the surface. Failure to remove all loose material, laitance, coatings, curing compounds, grease, oil, dirt, paint and other contaminants will result in failure of THIN-FINISH™ as a "bond coat".

The use of detergents, soaps and sweeping compounds is not recommended as the residue will create a film that will interfere with adhesion.

Once all loose material, laitance, coatings, curing compounds, grease, oil, dirt, paint and other contaminants that interfere with adhesion are removed, a mild muriatic acid solution is needed to apply a slight "etch" of the surface, kill and bacteria and to adjust the pH of the surface. Carefully pour one part muriatic acid into eight parts clean water. Use protective eye and skin equipment. Use a plastic watering container to flood the surface with the acid and water solution and allow to fizz for three to five minutes. Do not allow the solution to dry. If the surface begins to dry, spray with water until the surface can be neutralized.

To neutralize the acid and water solution and adjust the pH, carefully pour one part ammonia into eight parts water. Using a plastic watering container, flood the surface with the ammonia and water solution and allow to sit three to five minutes and rinse thoroughly with water.

**14. MIXING:**

Weather conditions should be taken into consideration before mixing. Recommended application temperature for THIN-FINISH™ is between 40° and 90° F (4° and 32° C). Ideal application temperature for THIN-FINISH™ is 70° F (21° C). If the ambient temperature is forecast to drop below 40° F (4° C) within 36 hours after the application of THIN-FINISH™, the finish must not be installed.

The volume of water added to the mix must be accurately measured. Overwatering may cause a weakening of overlay surface and surface cracking. Underwatering will decrease workability and adhesion.

It is critical that all components are added in same sequence and thoroughly mixed. Water is first added to the mixer, followed by



the overlay material. If the overlay material is added to the water, clumps may form in the mix and performance will be sacrificed. Mix the overlay material three to four minutes for consistent blending, allow to "false set" for 5 to 15 minutes and re-mix. It may become necessary to add a very small amount of water when re-mixing after the "set". Please note that this is a critical step to the mixing process. Failure to strictly comply with these mixing instructions may result in loss of abrasion and water resistance as well as a loss of adhesion.

#### 15. INSTALLATION:

##### A. THIN-FINISH™ as a "bond coat" for TEXTURE-PAVE™:

The surface area should be divided into smaller work sections using walls or joints lines depending on the amount of overlay experience the installer has.

As with most cementitious products, existing cracks or joints in the substrate will reflect through the overlay. Joints must be reproduced and cracks must be repaired as best possible during the application process. Any delay in the reproducing of the joints may result in a loss of adhesion along the joint, crack, expansion or edge.

THIN-FINISH™ mix as a "bond coat" must be applied to the cleaned and prepared concrete surface before TEXTURE-PAVE™ is applied. The concrete should be misted wet without puddling water.

Mix the THIN-FINISH™ material with clean cold water to form a smooth consistency similar to pancake batter. Apply the material to the surface with an approved neoprene squeegee or by trowel, without puddling the material. Additional information is available in the Elite Crete Systems Product Information PI-30 TEXTURE-PAVE™.

Care should be taken to ensure the THIN-FINISH™ material will not become dry prior to the application of the TEXTURE-PAVE™ overlay. This wet to wet bond is critical to adhesion and wear. If the "bond coat" dries before the application of overlay, apply an additional "bond coat".

The TEXTURE-PAVE™ overlay material must be applied immediately after mixing is complete. Apply at a thickness of 1/8" (3 mm) to up to a maximum of 1" (25 mm) depending on the depth of the THIN-PRINT™ Mat or needed build-up.

If additional buildup is needed, another THIN-FINISH™ "bond coat" will be required prior to the application of the TEXTURE-PAVE™ mix. Additional information is available in the Elite Crete Systems Product Information PI-301 TEXTURE-PAVE™.

##### B. THIN-FINISH™ as "finish or broom coat":

A dry coat of THIN-FINISH™ must first be applied and surface imperfections must be filled to expectations.

Mix and apply an additional coat of THIN-FINISH™. This coat may be immediately "broomed" or left as a smooth "finish" coat. Brooming to late will result in a loss of broom texture.

If THIN-FINISH™ is to be "broomed", the material must be immediately broomed before the material has a chance to dry.

Use a standard edging tool to detail the sides of the surface once the material has become slightly firm.

##### C. THIN-FINISH™ as a "splat texture" finish:

A dry coat of THIN-FINISH™ as a base/skim coat must first be applied and surface imperfections must be filled to expectations. This coat will be seen as the grout line color if filament tape or stencils are used. Take this into consideration when choosing color.

The THIN-FINISH™ material will be slightly thicker when used as a splat texture coat versus a base/skim coat.

#### 16. DETAILING and SAWCUTTING:

Once the THIN-FINISH™ material is just firm enough to take light foot traffic the imperfections along the joints and edges should be detailed and touched up.

Detailing must take place within four to six hours after the application process.

When saw cutting control joints, the sawcutting must be done before cracking occurs but when the surface has reached sufficient strength not to be damaged, a minimum of 24 hours after the process was completed.

THIN-FINISH™ gains strength similar to concrete. The surface can be opened to traffic when it reaches sufficient strength not to be damaged, a minimum of 48 hours for light traffic. A minimum of 3 to 7 days for normal traffic. A full 28 day cure is required before opening to heavy traffic. Protect the curing surface from other construction trades.

#### 17. STAINING and ANTIQUING:

If THIN-FINISH™ is to be stained or antiqued with either ULTRA-STONE™ Stain or CHEM-STONE™ Stain, experimentation is required to produce the proper combination of colors and variations.

THIN-FINISH™ must be firm enough to take foot traffic and cured 8 to 12 hours prior to the application of ULTRA-STONE™ Stain.

THIN-FINISH™ must be firm enough to take foot traffic and cured 16 to 24 hours prior to the application of CHEM-STONE™ Stain. Note: If THIN-FINISH™ has not been allowed to cure 14 days, CHEM-STONE™ may not achieve maximum color intensity.

Additional information is available in the Elite Crete Systems Product Information PI-144 ULTRA-STONE™ Stain and PI-145 CHEM-STONE™ Stain.

The stained or antiqued surface must be protected from all traffic until it is sealed.

#### 18. SEALING:

THIN-FINISH™ Overlays must be sealed, coated or painted for ease of maintenance and to protect the surface, using materials that have demonstrated compatibility. Seal or coat as soon as the surface can be walked on, approximately 16 to 24 hours after the application process was completed. Additional information is available in the Elite Crete Systems Technical Data TD-414 SEALER OPTIONS.

All sealed surfaces should be inspected to verify and approve installation and safety, including wet and dry slip resistance prior to opening the area to traffic.

#### 19. AVAILABILITY:

THIN-FINISH™ is marketed nationwide and internationally, directly to training installers through strategically located authorized distributor and suppliers.

#### 20. WARRANTY SUMMARY:

For the complete warranty statement and important limitations, read the Material Safety Data Sheet and Warranty. Generally, Elite Crete Systems, Incorporated represents and warrants only that its products are of consistent quality. No other oral or written statement is authorized. Any liability is limited to refund or replacement of the defective product. The end user shall determine product's suitability and assume all risks and liability.



Products & Systems for Architectural Concrete Finishes & Concrete Restoration

## TECHNICAL DATA: THIN-FINISH™

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Product Name: THIN-FINISH™ Overlay – Part of the Pre-Mixed Overlay System  
Product Class: Dry, Redispersible, Cement based Mortar

### Use Applications:

- For thin surface repairs and resurfacing of concrete substrates
- For creating splatter/hoppergun applications, knockdowns, base/skim coats, broom finishes, seamless interior flooring, stenciled cement and more
- For creating repair and patching mixes for concrete surfaces

### Key Features:

- Better overall performance than most other resins, modifiers and polymers, including: Acrylic, polyvinyl acetate, styrene and silicone
- Provides a permanent bond (with correct substrate preparation on stable concrete surfaces above grade)
- Increased levels of finishes moisture resistance, flexural and tensile strengths
- Increased texturing capabilities
- Exceptionally long pot life
- Increase versatility and application range
- Can be colored with PORTION CONTROL COLORANT™ for custom coloring
- Can be colored with ULTRA-STONE™ Antiquing Stain for custom coloring

### Product Properties:

- Appearance – Fine Powder
- Smell – N/A
- Nonvolatile Content % - N/A
- GT Temperature – N/A
- Flammability - N/A
- Weight, Lb. Per stock container – 55 lbs.
- Application temperature - 40° - 100° F
- Cured - 28 days (initial 3-7dry days)
- Resistance to moisture deterioration - Good,
- Resistance to weather, including UV and freeze/thaw cycles - Excellent

### Available Packaging:

- Stock – 55 lbs. bags, 56 bags per pallet
- Available in White and Gray
- Special Order - Inquire

### Suggested Storage:

- Keep Dry
- Shelf Life - 6 months to a year

The information herein is general information to assist our customers in determining whether our products are suitable for their specific applications. Our products are intended for sale to commercial and industrial customers. We require that customers should inspect and test our products before use to satisfy themselves as to the content and suitability for the applications they intend to use our products for. **Nothing herein shall constitute any warranty expressed or implied, including any warranty of merchantability or fitness for a particular purpose, nor is any protection from any law or patent to be inferred.** The exclusive remedy for all proven claims is replacement of our materials and in no event shall we be liable for incidental or consequential damages.

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